Human-Robot Collaboration for Healthcare: Sociotechnical Insights on Development and Integration

Amirhossein Asadi

A thesis submitted for the degree of

Doctor of Philosophy

The Australian National University

School of Cybernetics

June 2026

This work is dedicated to dignity, freedom, and hope –
and to all those who keep them alive.

Disclaimer

I hereby declare that the work undertaken in this thesis has been conducted by me alone, except where indicated in the text. I conducted this work between July 2021 and March 2026, during which period I was a PhD student at the Australian National University. This thesis, in whole or any part of it, has not been submitted to this or any other university for a degree.

Amirhossein Asadi

18 June 2026

Acknowledgements

This thesis took shape through the support, trust, and generosity of many people.

First and foremost, I would like to express my deepest gratitude to my primary supervisor, Associate Professor Liz Williams. Thank you for believing in me at times when I doubted myself, and for trusting me as I found my way through this work. Your mentorship, generosity, and encouragement shaped this PhD in important ways.

I am also deeply grateful to my associate supervisors, Professor Damith Herath and Professor Glenda Caldwell. Thank you for the confidence you gave me and for your thoughtful support, kindness, and encouragement. My sincere thanks also go to Professor Chris Danta, Chair of my panel, for your support and for helping create the conditions in which this work could develop.

A special thank you to Professor Alex Zafirglou, whose support began even before I joined the PhD program. Thank you for all you did early on, and for the encouragement you continued to offer over the years. I am also very grateful to Distinguished Professor Genevieve Bell, Professor Katherine Daniel, Dr Paul Wong, Dr Ben Swift, and all amazing people at the School of Cybernetics for fostering an environment in which this work could take shape.

I acknowledge the use of ChatGPT, Overleaf's integrated AI assistant, and Microsoft Copilot for proofreading, grammar checking, clarity improvements, formatting-related suggestions, and language editing support. These tools were not used to generate original research content, analysis, or interpretations. I reviewed all AI-assisted suggestions and take full responsibility for the final thesis.

I also acknowledge funding support from the Australian National University through the Higher Degree Research (HDR) Fee Merit Scholarship, the University Research Scholarship, and the Florence McKenzie Supplementary Scholarship in a New Branch of Engineering.

To my PhD cohort, and especially Lorenn Ruster, Ned Cooper, Memunat Ibrahim, Tom Chan, Kathy Reid, Danny Bettay, and Charlotte Bradley, thank you. I feel very fortunate to have shared this experience with you. Your friendship, support, and understanding made this journey easier and far less lonely.

To my colleagues at the Australian Cobotics Centre — Müge Belek Fialho Teixeira, Matthias Guertler, Alan Burden, Yuan Liu, Jasper Vermeulen, Victor Poulsen, and

Bochao Xu — thank you. I am grateful to have been part of a place where ideas were shared openly and where people looked out for one another.

My sincere thanks to my collaborators, Mr. Grant Shaw and Dr Balaji Bhikshandi. Thank you for your trust, your time, and the generosity with which you worked with me. It was a privilege to learn from and work alongside you. I would also like to thank University of Canberra Hospital and its staff for their support and involvement in this research.

I would like to sincerely thank the participants in this research for their time, insights, and willingness to take part. Their contributions were central to this thesis.

To my family and friends back home — Maman, Ghamar, Ali, Javad, Zahra, Bagher, Mehdi, Majid, Saeid, Mahsa, Negin, Saeid, Mohammad, Sarina, Parsa, Bahar, Nima, Matin, Mahnia — thank you. Even across the distance, your love and support remained with me. In difficult moments, the thought of you gave me reason to keep going. This work carries more of you than these words can properly express.

And finally, to my wife, Zahra. Thank you for your patience, strength, and constant belief in me. You were beside me through every stage of this PhD, and your support held me up more than you know. I owe more to you than I can put into words.

Publications and Contribution Statement

Several components of the research undertaken during candidature have been disseminated through peer-reviewed publications and manuscript submission. These publications represent selected components of the broader research program presented in this thesis:

1. Asadi, A., Herath, D. C., Shaw, G., Caldwell, G., & Williams, E. (2025). *Redrawing Boundaries: Systemic Impacts of Rehabilitation Robots in Clinical Care Settings.* In *Proceedings of the 2025 20th ACM/IEEE International Conference on Human-Robot Interaction (HRI)* (pp. 1216–1220). IEEE.

This paper received the ***Best Late-Breaking Report Award*** *at HRI 2025.*

I was the lead author on this publication. I led the study design, data collection, qualitative analysis, interpretation of findings, preparation of the manuscript, and drafting and revision of the paper. My co-authors contributed to the development of the research direction, provided supervisory and interdisciplinary input, supported the interpretation of the findings, facilitated access to participants and hospital processes, assisted with site-related arrangements, and reviewed and edited the manuscript for publication.

2. Asadi, A., & Williams, E. T. (2024). *Preparing for change: Reflections on technology design research in real-world healthcare contexts.* In *Proceedings of the 36th Australian Computer-Human Interaction Conference.*

I was the lead author on this publication. I developed the core argument of the paper, led the preparation of the manuscript, and was primarily responsible for framing the discussion in relation to the doctoral research and for drafting the majority of the paper. My co-author made substantial contributions to the writing of the manuscript, to the synthesis of the experiences and reflections presented from her perspective, and to the refinement of the paper's structure and argument, and was actively involved in supervision, feedback, and revision of the final version.

3. Asadi, A., Williams, E. T., Bikshandi, B., Shaw, G., & Herath, D. C. *Acceptance of Human-Robot Collaboration in Hospitals: Trust, Risk, and Ethics in Focus.* Preprint. Currently under review. DOI: 10.21203/rs.3.rs-9127773/v1.

I was the lead author on this manuscript. I led the conceptual development of the study, data collection, analysis and interpretation of the findings, and drafting of the manuscript. My co-authors contributed intellectual input, disciplinary expertise, feedback on the framing of the manuscript, facilitated access to participants and hospital processes, assisted with site-related arrangements, and provided critical reviews of drafts prior to submission.

Abstract

This thesis examines human–robot collaboration (HRC) in healthcare through a sociotechnical lens. It positions robots not as isolated technologies, but as components of complex clinical systems shaped by human actors, work routines, infrastructures, organisational arrangements, and regulatory contexts. Although HRC is often framed as a response to workforce shortages, many deployments fail to achieve effective, acceptable, and sustained integration.

To better understand why HRC deployments struggle in practice and how these challenges can be addressed, this research is structured around three interrelated questions. First, it explores how HRC technologies are developed and introduced into healthcare settings. Second, it examines the factors that influence stakeholder acceptance of HRC technologies in healthcare contexts. Third, it considers how knowledge gained from these sociotechnical processes can be translated into practical guidance for the design and integration of HRC technologies in healthcare.

Guided by a pragmatic paradigm, the thesis adopts a mixed-methods approach within a Design Science Research Methodology. It combines qualitative and quantitative approaches, including interviews with experts in healthcare technology, a hospital-based quantitative acceptance study, and two in-depth qualitative case studies. Findings from the first two studies are synthesised into the STEER-H framework (Sociotechnical Engineering for Effective Robotics in Healthcare). The framework is then demonstrated and refined through two contrasting case studies: a prospective HRC design for a hospital rapid response system and a retrospective examination of an established rehabilitation robot in routine clinical use.

The expert interviews show that introducing HRC into care settings is shaped by a tightly interwoven stakeholder ecosystem, the need for context-aware design that fits work-as-done, and broader constraints including regulation, funding, and professional norms. The quantitative acceptance study indicates that acceptance is influenced by contextual factors such as trust, perceived risk, and ethical concerns, reflecting the high-stakes and accountability demands of clinical work. Overall, the findings suggest that effective HRC depends on alignment across multiple dimensions identified in STEER-H — stakeholder, institutional, and ecosystem. The framework provides an analytic lens for anticipating integration challenges, structuring design and implementation work, and identifying where targeted interventions are required.

The thesis contributes the STEER-H sociotechnical framework, grounded in healthcare robotics literature, expert perspectives, and empirically identified acceptance determinants; an empirically tested acceptance model that estimates the effects of trust, perceived risk, and ethical concerns alongside functional and workflow-related factors; and an in situ evidence base spanning two distinct clinical contexts and stages of adoption. In sum, this thesis advances a sociotechnical foundation for embedding HRC within complex healthcare systems.

Contents

List of Figures

List of Tables

Preamble

This research is grounded in my engineering experience. For years, I assumed that if we could build a system that worked reliably, we would be most of the way there. That view formed during the five years I spent developing medical and robotic technologies, including a lower-limb rehabilitation robot intended to support mobility for people with spinal cord injuries. The deeper I got into that work, the more I realised the hardest part wasn't making the system perform. It was making it belong in the world it was meant for.

I approached the rehabilitation robot project with an engineer's mindset, one grounded in defining the problem, building prototypes, testing, iterating, and improving. Seen through that lens, the project appeared to be *successful*. We advanced from early prototypes to a functional system that behaved as designed, and it became easy to imagine that moving into healthcare settings would simply be the next step.

In practice, however, the transition into a clinical environment presented a fundamentally different challenge. The robot could work, and yet the setting pushed back in ways we had not anticipated, or even considered. Workflows, organisational structures, space, equipment, infrastructure, training requirements, coordination demands, and scheduling constraints shaped what was practical, revealing that our definition of "success" had only captured part of the picture. There were also questions about risk, accountability, regulation, and ethics, all of which shaped not only how we could deploy the technology but whether it could be sustained at all.

Those experiences stayed with me because they made me more attentive to everything that surrounds a technology for healthcare. In that project, I treated the robot as the primary object and the clinic as the endpoint. In reality, it was never just a destination. The clinic was a living system of people, routines, obligations, and trade-offs and in that context, even a small addition (a new device, a new training, a new step) had to earn its place.

To achieve that goal, I needed a way of thinking that could shift focus from components and functions to the broader set of relationships and routines the technology would have to live within. I therefore undertook this research within the Australian National University's School of Cybernetics. The School approaches cybernetics as a transdisciplinary way of engaging with complex systems by attending to their components, connections, and dynamics, and by keeping the relationships between technological, human, and environmental elements in view.

This orientation provides a fitting home for the present thesis. I focus on human-robot collaboration in healthcare, a concept with great potential that is often discussed in abstract terms, detached from the realities of clinical labour, and too rarely attentive to how non-technical factors shape the role a robot can realistically play and the ways that role can be carried out in practice. My aim is to make those constraints visible to the people building these systems, engineers like myself, and to offer approaches that help them steer through these challenges.

I'm writing from the position of someone who still cares deeply about engineering, but is now more cautious about what gets lost when complex practice is reduced to technical specifications. What follows is an effort to foreground the sociotechnical work that makes human-robot collaboration possible in care settings and to offer a framework for thinking about it.

Chapter 1

Introduction

If you open a search engine today and enter the terms *technology*, *future*, and *healthcare*, the resulting narratives overwhelmingly frame technology as a transformative force for health systems around the world. Innovations such as artificial intelligence (AI), robotics, digital health platforms, and wearable devices are routinely presented as solutions to a wide range of challenges, from clinical diagnosis and surgical intervention to nursing practice and aged care. Across these accounts, technology appears as a largely neutral and universally applicable instrument, expected to improve care through gains in efficiency, accuracy, and cost reduction.

However, such accounts tend to underplay the complex social, organisational, and professional arrangements through which care is delivered. When this complexity is overlooked, technology can fail to deliver its intended benefits or even create new problems. This tension invites a closer consideration of how technological change unfolds within everyday care environments. Rather than asking only what advanced systems are capable of, it becomes necessary to examine how such technologies are introduced, interpreted, and integrated into the situated practices of care, and how they are designed — or should be designed — to fit the real-world healthcare contexts in which they operate.

In this thesis, I examine the intersection of healthcare and advanced technological systems, with particular attention to *Human–Robot Collaboration* (HRC), understood as situations in which humans and robots work together in shared tasks, environments, or workflows. This inquiry is grounded in a sociotechnical systems (STS) approach, focusing on how technical capabilities, social dynamics, organisational arrangements, professional roles, and everyday work practices come together in healthcare contexts. The aim of this research is to inform designers, developers, and integrators about the sociotechnical considerations that shape the effective and meaningful use and adoption of robotic technologies in healthcare.

To establish the context for this research and clarify its significance, the following sections outline the broader healthcare context, as well as the background, objectives, and scope of the study.

> ”Merely proving that you have powerful technology is not sufficient. [...] Prove to me that it will actually do something useful — that it will make my life better, and my patients’ lives better.” Martin Kohn, a former IBM medical scientist, April 2019 (quoted in Faheem and Dutta (2023))

1.1 Technology in Contemporary Healthcare

Contemporary enthusiasm for technology in healthcare is closely tied to the structural pressures facing health systems, most notably the global shortage of healthcare workers. The World Health Organization (WHO) has long warned that workforce constraints limit access to essential services in many countries; even before the COVID-19 pandemic, it projected (in 2016) a global shortfall of 18 million health workers by 2030 (World Health Organization 2022). These workforce pressures intersect with a wider set of systemic challenges, including constrained budgets, high levels of clinician burnout, and escalating expectations to deliver more complex care with limited resources. Recent industry analyses suggest that health system leaders anticipate these pressures will intensify, particularly as they contend with population ageing, increasing care complexity, and enduring weaknesses in system resilience (Deloitte 2025). In this context, health system strengthening has emerged as a central policy priority, shaping how governments and institutions evaluate potential interventions, especially in relation to global commitments such as Sustainable Development Goal 3, which aims to promote healthy lives and well-being for all (United Nations 2015).

At the global level, policy frameworks increasingly position emerging technologies as central instruments for responding to these systemic pressures. The WHO’s global digital health strategy situates artificial intelligence, robotics, data analytics, and connected devices within broader efforts to improve health outcomes across diverse social and economic contexts (World Health Organization 2025). Complementing these strategic documents, policy-oriented analyses seek to map how such technologies may function in practice. A review conducted by the European Commission’s Joint Research Centre under the AI Watch programme identifies a growing range of current and near-term AI applications in healthcare, including administrative support, diagnostics, clinical decision support, and more personalised and preventive models of care (Gómez-González 2020). Estimates of potential impact are frequently ambitious. A Deloitte report focused on Europe suggests that AI-enabled technologies spanning wearables, diagnostic imaging, virtual health assistants, and robotics could save up to 403,000 lives annually, free between 1.7 and 1.9 billion hours of professional time, and reduce healthcare costs by €170 to €212 billion per year (Deloitte 2021).

A similar story appears in Australia, the context in which this research has been carried out. Policy documents, industry reports, and media commentary consistently suggest that AI, robotics, and related technologies will shape the future of health services and systems. The National Robotics Strategy identifies areas where robotics already contributes or is expected to contribute to care, including diagnostic support, surgical assistance, and rehabilitation, and links these applications to safer workflows and workforce relief (Department of Industry Science and Resources 2024). State-level initiatives reinforce this direction. As part of the HealthQ32 reform agenda, Queensland Health has developed a series of plans that set out a deliberate pathway for technology adoption. The Statewide Robotics Plan 2024–2029, for example, outlines a five-year roadmap for integrating robotic systems across hospital and health services, explicitly linking technological investment to objectives of patient benefit, operational efficiency, and long-term system sustainability.

Empirical research on technology in healthcare lends further support to these policy ambitions, although with varying levels of evidentiary strength. A growing body of literature suggests that artificial intelligence and robotics can improve clinical outcomes, reduce workload pressures, and enhance patient experience (Hazarika 2020; Kyrarini et al. 2021; Meskó et al. 2018; Buntin et al. 2011). For example, studies of AI-enabled clinical decision support systems report improvements in decision quality and reductions in error rates, contributing to safer care and fewer adverse events (Amarasingham et al. 2009; Campanella et al. 2016). Research on robotic systems similarly points to benefits in areas such as surgical precision, rehabilitation support, and patient independence, as well as assistance for healthcare professionals in specific workflows and care environments (Kyrarini et al. 2021; Stasevych and Zvarych 2023).

Viewed together, these signals from policy, industry, and research indicate a growing interest in — and action toward — leveraging technology to support change across the healthcare sector. Yet this growing momentum also invites a more cautious question: are these visions or efforts consistently effective or successful in practice?

While many technologies show promise in trials, pilots, or early evaluations, their translation into sustained improvements within everyday healthcare settings is uneven and uncertain. Evidence from implementation research suggests that technological interventions often fall short of expectations once they encounter the realities of clinical work, organisational routines, and institutional constraints (Greenhalgh et al. 2017; Topol 2019). Trisha Greenhalgh, one of the leading scholars in technology adoption in healthcare, estimates that roughly 80 percent of technology-supported change efforts in health and social care fail to achieve meaningful adoption (Greenhalgh 2019). While this estimate is “unverified”, it underscores the difficulty of translating technological innovation into durable practice within complex care environments.

High-profile initiatives from large technology firms illustrate these challenges in concrete terms as emblematic examples of broader implementation barriers. Google Health, for instance, was discontinued in 2011 after failing to demonstrate clear improvements in outcomes or achieve integration within routine clinical workflows (Spil and Klein 2014; Mora 2012). Similar themes appear in critiques of early AI-enabled systems such as IBM Watson for Oncology, which promised to transform cancer diagnosis and treatment planning. Its advanced natural language processing and access to large clinical datasets did not prevent the system from producing recommendations that conflicted with clinicians’ judgments or failed to reflect local practice guidelines (Faheem and Dutta 2023; Di Nucci et al. 2019). Other initiatives followed a comparable trajectory. The SurgiBot surgical platform, developed as a lower cost alternative to established robotic systems, failed to secure FDA clearance and was subsequently abandoned as its developers redirected resources toward platforms with clearer regulatory and commercial viability (Densford 2016). Commentators identify a recurring set of factors behind the limited uptake of new technologies in healthcare, including poor alignment with clinical workflows, regulatory barriers, unclear incentives, organisational resistance, weak value propositions, concerns about privacy and data governance, limited provider involvement, and low user trust (Coiera et al. 2016; Sittig et al. 2020). Several of these themes are examined in detail in the literature review chapter and form the foundation for the research questions addressed in this study.

1.2 Sociotechnical Systems Approach

The challenges described above draw attention to dynamics beyond technical design and to interactions between technologies and the organisational, professional, and institutional conditions of care. Sociotechnical systems theory provides a way of engaging with these interactions by treating technical systems not as self-contained solutions, but as components of broader sociotechnical environments. From this perspective, the social and technical systems of work are interrelated and cannot be meaningfully decoupled (Trist and Bamforth 1951; Trist 1981). This orientation has had a sustained influence on research examining the implementation and use of healthcare technologies, particularly in complex clinical environments.

STS[1] research highlights how factors such as professional norms, organisational routines, regulatory requirements, information infrastructures, and informal work practices shape how technologies are taken up and sustained in practice (e.g., Sittig and Singh 2010; Salwei and Carayon 2022; Bonet Olivencia and Sasangohar 2023; Blijleven et al. 2022). It is this sociotechnical perspective that I adopt in this thesis to examine how healthcare technologies, and in particular human-robot collaboration, come to function in practice. Adopting a sociotechnical orientation shifts attention away from questions of technical capability or performance in isolation, and toward the conditions under which technologies are integrated into everyday work. From this perspective, such difficulties are not peripheral implementation problems, but central to understanding how technologies encounter existing forms of work.

In choosing this approach, my research aligns closely with the sociotechnical systems analysis agenda proposed by Carayon et al. (2011), which argues that improving the quality of care requires considering the full *work* system: people, tasks, technologies, environments, and organisations. It also builds on Blandford's call to move beyond narrow technical concerns and engage with the broader social and organisational conditions that shape how technologies are experienced and sustained in practice (2019). In this sense, the study also responds to calls within the sociotechnical literature to apply systemic analysis to emerging technological domains and complex societal challenges, including healthcare and other large-scale service systems (Davis et al. 2014).

1.3 Narrowing the Focus: Human-Robot Collaboration

Having established the broader sociotechnical approach of this thesis, I now return to HRC as the focal point of this study. While the preceding discussion provides important context, treating healthcare technologies as a unified category risks obscuring differences that are crucial for understanding how technologies function in practice. Healthcare technologies vary in their material form, degrees of autonomy,

[1] It is worth noting that the acronym "STS" is sometimes used to refer to *Science and Technology Studies* but in this thesis, STS refers to *sociotechnical systems*.

and modes of interaction, each of which shapes how they are designed, introduced, and embedded within clinical work. Reflecting on this diversity, this thesis focuses on HRC in order to examine these dynamics in greater depth.

Here, I refer to HRC as situations in which humans and robotic systems work together within shared tasks and environments toward common goals (Gervasi et al. 2020; Valori et al. 2021; Weerarathna et al. 2023; Liu et al. 2024). Unlike more traditional forms of automation, where machines are intended to substitute for human labour or operate with minimal human involvement, HRC is oriented toward augmentation rather than replacement. In healthcare contexts, this collaboration may involve physical co-presence, task sharing, or cognitive and decision support across activities such as patient handling, logistics, rehabilitation, and clinical assistance (Weerarathna et al. 2023).

Several considerations motivate the selection of HRC as the focal domain of this thesis. First, HRC is increasingly positioned as a response to workforce pressures in healthcare, particularly in contexts characterised by staff shortages, high physical demands, and repetitive or ergonomically challenging tasks (Weerarathna et al. 2023; Ait Ameur et al. 2024). As robotic systems are introduced into clinical environments under the banner of collaboration rather than automation, HRC is likely to gain prominence not only as a technical approach but also as a conceptual framing that shapes expectations of what robots are meant to do in care. This growing attention makes it timely to examine these systems.

Second, the interactive and physically proximate character of HRC intensifies its sociotechnical dimensions. Because HRC systems are embedded directly within clinical work, their operation is tightly coupled to organisational routines, professional roles, spatial arrangements, and informal practices. This embeddedness makes the sociotechnical dynamics of HRC particularly visible and consequential, positioning them as central rather than peripheral concerns for those involved in system development and integration.

Finally, while sociotechnical perspectives have been widely applied to the study of information systems and digital technologies in healthcare, their application to HRC remains comparatively limited. This relative absence narrows current understandings of how HRC systems intersect with established forms of clinical work and institutional organisation. Therefore, addressing this gap constitutes a central objective of this thesis.

1.4 Research Objectives

Bringing together the threads introduced above, this thesis is guided by the overarching objective of developing a situated understanding of how human-robot collaboration technologies are developed, introduced, and sustained within healthcare settings. Rather than treating HRC systems as discrete technical interventions, the thesis examines how their design and integration are shaped by sociotechnical factors. Through this lens, the research seeks to generate insights that are relevant to those involved in the design and integration of HRC systems in healthcare.

1.5 Methodological Approach

The research objectives outlined above call for a methodological approach capable of engaging with phenomena that are situated, contingent, and deeply shaped by context. In response, I adopt a mixed-methods methodological approach guided by Design Science Research (DSR) (Hevner et al. 2004) and underpinned by a pragmatist philosophical stance. This combination reflects a deliberate effort to engage systematically with complex sociotechnical arrangements while producing knowledge that remains meaningful and usable in practice.

DSR provides an orientation for the iterative design and development of a research artefact — here, a sociotechnical framework — through cycles of problem framing, design, and evaluation (Hevner et al. 2004; Hevner 2007). In this study, these cycles are informed by empirical investigations of healthcare contexts. Insights from qualitative and quantitative methods are synthesised to develop the framework, while qualitative case studies are used to assess its relevance and usability.

A pragmatist philosophical stance complements this orientation by emphasising the practical consequences of research and legitimising the use of multiple forms of evidence in addressing applied problems. Pragmatism supports methodological pluralism and encourages attention to what works, for whom, and under what conditions (Creswell and Creswell 2017). This stance is particularly well suited to healthcare contexts, where complex systems, diverse stakeholder perspectives, and real-world implementation challenges require flexible, problem-focused inquiry.

Further details of the research design, data collection, and analytical procedures are presented in chapter 3.

1.6 Scope of the Study

This study is defined by a set of deliberate boundaries that shape its empirical focus, analytical commitments, and methodological approach. These boundaries reflect considered decisions about what the thesis examines in depth.

1. This study is situated within healthcare settings in which healthcare professionals provide direct care services to patients. Throughout the thesis, the term *healthcare settings* refers primarily to institutional environments such as hospitals, outpatient clinics, rehabilitation facilities, and other organised health service contexts where care is delivered as part of formal clinical and organisational arrangements.
2. The empirical focus centres on stakeholder groups who are directly involved in, or affected by, the use of HRC systems. These include healthcare professionals (such as clinicians, nurses, and allied health staff), patients, and other relevant actors involved in the development, deployment, and use of robotic systems. I describe the specific stakeholder groups engaged, and their roles within each phase of the research, in detail in the relevant chapters.
3. I do not intend to examine every dimension of HRC in exhaustive detail. Issues such as safety, trust, privacy, data governance, and ethical considerations are widely recognised as important and continue to evolve as areas of research. These issues are acknowledged where they intersect with sociotechnical aspects of this thesis, but they are not treated as primary analytical objects in their own right. I make this choice deliberately, as each of these areas warrants dedicated investigation beyond the scope of this project.
4. The empirical work reported in this thesis is grounded in healthcare settings within Australia, where fieldwork was conducted through partnerships with hospitals and health services. The findings, therefore, reflect the regulatory, organisational, and institutional characteristics of the Australian healthcare system. At the same time, the thesis draws on international literature and cross-contextual insights, particularly in the literature review and discussion chapters, to situate the findings within a broader global landscape of healthcare robotics.

1.7 Contributions

This thesis makes three primary contributions, which are briefly outlined here and discussed in detail in the Chapter 10.

First, it contributes a healthcare HRC-specific sociotechnical framework, which makes explicit the multilevel factors shaping the design, integration, and use of robots in clinical work.

Second, this thesis contributes empirical knowledge about healthcare HRC through the development and testing of an acceptance model in a safety-critical hospital context, together with evidence from two contrasting in situ case studies.

Third, this thesis contributes practical and methodological guidance for healthcare HRC. Practically, it identifies actionable sociotechnical considerations for earlier and more effective design and integration of robotic systems in healthcare. Methodologically, it demonstrates a mixed-methods DSR approach that combines exploratory qualitative work, quantitative model testing, and case-based evaluation to generate both explanatory insight and usable design knowledge.

These contributions collectively advance a sociotechnical foundation for embedding HRC within healthcare settings.

1.8 Researcher Positionality

This section clarifies my position in relation to the research and the perspectives that shaped how the study was framed and interpreted. I did not enter the project as a neutral observer. My prior experience in developing robotic and medical technologies informed what I initially assumed would matter in the design and uptake of advanced systems, and it influenced the questions I asked and the kinds of explanations I found persuasive.

Across the project, my role shifted between insider and outsider positions. Drawing on Dwyer and Buckle's definition of the insider–outsider (2009), an *insider* is a researcher who shares relevant characteristics, roles, or experiences with participants, whereas an *outsider* is one who does not. Importantly, these positions are not fixed but relational and may be occupied simultaneously across different dimensions of identity and experience (Dwyer and Buckle 2009). I could participate comfortably in technical discussions with developers and engineers, while in clinical settings I often relied on participants to surface tacit routines, constraints, and priorities that are less visible from a design perspective. These shifts shaped the rapport I built with participants, what required explanation, and how I interpreted tensions between technical aspirations and practical care demands.

I have also chosen to write this thesis in the first person where appropriate. This is a deliberate decision to make my standpoint visible and to support accountability for the interpretive choices involved in producing the analysis. In qualitative research, claims to impersonal neutrality can obscure the researcher's role in shaping the questions asked, the relationships formed in the field, and the meanings drawn from the data. Writing in the first person therefore functions not merely as a stylistic choice, but as part of a reflexive practice that acknowledges knowledge as situated and the researcher's presence as integral to the production of the account (England 1994; Webb 1992).

1.9 Thesis Structure

This thesis is organised into several chapters that build on each other to present the research in a logical flow.

Chapter 2 reviews the literature that informs the thesis. It first clarifies the foundations and definitions of HRC, then presents a scoping review of empirical HRC research in healthcare to identify dominant themes and key gaps. The chapter also examines sociotechnical systems theory, technology acceptance models, and the wider healthcare robotics literature on barriers and facilitators, before bringing these strands together to establish the conceptual framing of the thesis and the research questions.

Chapter 3 sets out the research methodology. It explains the pragmatist research paradigm and the use of Design Science Research as the overarching design approach. The chapter also describes the mixed-methods strategy adopted in the thesis, including exploratory interviews, a quantitative acceptance study, and qualitative case studies, and explains how these forms of evidence are synthesised in the development and evaluation of the thesis artefact.

Chapter 4 presents the findings from the exploratory expert interviews and Chapter 5 addresses stakeholder acceptance of HRC in a hospital rapid response system context.

Chapter 6 develops the STEER-H framework. Drawing together the qualitative and the quantitative findings, this chapter presents the thesis artefact as a sociotechnical framework for HRC development and integration across stakeholder, institutional, and ecosystem layers.

Chapters 7 and 8 demonstrates and evaluates STEER-H through case studies.

Chapter 9 provides an integrative discussion of the thesis findings. It brings together insights from the exploratory interviews, acceptance study, framework development, and both case studies, synthesising them against the research questions and positioning STEER-H in relation to existing sociotechnical approaches.

Finally, Chapter 10 concludes the thesis by summarising its contributions to knowledge and practice, discussing its limitations, identifying directions for future research, and offering a closing reflection on the implications of this work for the development and integration of HRC in healthcare.

The thesis also includes a set of appendices that provide supporting materials for the empirical studies, including the scoping review methodology and results, codebooks, survey measurement items, and model assessment results.

Chapter 2

Literature Review

The purpose of this chapter is to explore and synthesise the bodies of literature that inform and contextualise this research. It begins by situating HRC within broader traditions of human-machine partnership and clarifying how the concept is used in this thesis. The chapter then presents a scoping review of empirical HRC research in healthcare to map the current field, identify dominant areas of focus, and highlight key gaps that motivate this study. Building on these findings, it introduces sociotechnical systems theory and technology acceptance models as complementary perspectives for understanding how HRC is developed, integrated, and sustained in practice. The chapter also reviews the wider healthcare robotics literature on barriers and facilitators across micro, meso, and macro levels, before bringing these strands together to establish the conceptual framing of the thesis and the research questions that follow.

2.1 Human-Robot Collaboration: Foundations and Definitions

HRC builds on a long intellectual tradition that understands humans and machines as complementary partners rather than competing agents. Early formulations such as Licklider's concept of Man-Computer Symbiosis (1960), Engelbart's work on Intelligence Augmentation (1962), theories of Distributed Cognition (Hutchins 1995), the framework of Joint Cognitive Systems (Hollnagel and Woods 2005), and later work on Human-Machine Teaming (Klein 2014; Seeber et al. 2020) all emphasise the coupling of human and technological capabilities to achieve shared goals, distribute cognitive and physical work, and extend human action in complex environments. HRC can be understood as a contemporary and embodied expression of this tradition, concerned with how humans and robotic systems work together in physical settings.

HRC has gained increasing attention in domains characterised by labour intensity, task complexity, and sustained human involvement (e.g., Arents et al. 2021; Burden et al. 2022; Ait Ameur et al. 2024). It is commonly used to describe configurations in which humans and robots work together in shared tasks, environments, or workflows, combining distinct but complementary capabilities in pursuit of a common objective (Arents et al. 2021; Weerarathna et al. 2023; Ait Ameur et al. 2024; Valori et al. 2021; Matheson et al. 2019; Gervasi et al. 2020). In contrast to traditional industrial automation, where robots are typically separated from human workers, HRC emphasises closer spatial, temporal, and functional coupling between human and robotic action.

The literature commonly distinguishes several forms of human-robot working arrangements according to the degree of task and space sharing involved. These range from *coexistence*, where humans and robots operate in the same environment without pursuing a shared goal, to *cooperation*, in which they contribute to a common objective while maintaining separate roles, and finally to *collaboration*, where humans and robots work simultaneously on the same task or object within a shared space (Arents et al. 2021; Hentout et al. 2019; Burden et al. 2022; Bauer et al. 2008). While these distinctions are analytically useful, they are not always clear-cut in practice, particularly in complex work settings where patterns of coordination may shift over time.

Central to contemporary discussions of HRC is the concept of the *collaborative robot*, or *cobot*, a term introduced in the 1990s by Edward Colgate and Michael Peshkin (Peshkin and Colgate 1999; Colgate et al. 1996). Cobots are commonly described as a subclass of robots designed to enable safe and effective work alongside humans in shared workspaces. Unlike conventional industrial robots, they incorporate safety-related features such as power and force limiting, speed and separation monitoring, safety-rated monitored stops, and hand-guiding functions, which allow physical proximity and, in some cases, direct contact with human collaborators (Arents et al. 2021; Burden et al. 2022).

At the same time, recent scholarship has questioned whether the term *cobot* remains conceptually precise when applied across a widening range of robotic systems and application domains. Early uses of the term were closely associated with lightweight, arm-based manipulators in manufacturing, but this narrow framing does not fully capture the diversity of robotic systems now discussed under the banner of collaboration. As Guertler et al. argue, defining cobots primarily in terms of form factor or domain of use can obscure their broader functional role within human-robot systems (2023). For this reason, in this thesis, I generally use the broader term *HRC* rather than *cobot* or *collaborative robot*, unless referring specifically to literature or systems that use those labels.

Finally, artificial intelligence is broadly understood as a machine-based capability that uses input data to generate outputs such as predictions, recommendations, content, or decisions that can influence physical or virtual environments (Organisation for Economic Co-operation and Development 2024). In many contemporary HRC systems, AI plays an important role in enabling robots to perceive environments, recognise patterns, support decision-making, and adapt to human actions, thereby influencing the quality and feasibility of collaboration. At the same time, HRC is not defined by AI per se. Rather, it refers more broadly to forms of collaborative work between humans and robotic systems in shared tasks, spaces, or workflows. In this thesis, AI is therefore treated as an increasingly important enabling capability in HRC, rather than as a defining feature of all HRC systems. Its growing incorporation into robotic systems nevertheless raises important questions around transparency, trust, accountability, and user acceptance, particularly in high-stakes healthcare environments.

2.2 Empirical Literature on HRC in Healthcare: A Scoping Review

In healthcare, HRC systems are typically framed as means of supporting clinicians and caregivers by taking on repetitive, physically demanding, or time-intensive tasks, while preserving human responsibility for clinical judgement, decision-making, and patient interaction (Ait Ameur et al. 2024; Weerarathna et al. 2023). Across the literature, commonly discussed applications include patient handling and mobility support, rehabilitation, medication delivery, telepresence, and hospital logistics (Ait Ameur et al. 2024; Weerarathna et al. 2023). In these contexts, robots are often positioned as contributing strength, endurance, and precision, while humans contribute contextual judgement, empathy, and adaptability (Buxbaum et al. 2019; Ait Ameur et al. 2024; Weerarathna et al. 2023).

Despite the growing body of conceptual and normative literature on HRC in healthcare, the empirical basis of this field remains less clearly consolidated. Existing reviews often emphasise technological capabilities or application areas, but provide more limited insight into how HRC is actually defined, designed, operationalised, and studied in practice across healthcare settings.

To address this gap, I conducted a scoping review to identify and characterise empirical studies of HRC in healthcare contexts. The review followed the methodological guidance for scoping reviews and was reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) (Tricco et al. 2018). The full scoping review protocol, including the methodological framework, search strategy, inclusion and exclusion criteria, screening process, and the rest of the results, is provided in Appendix A. In this section, I will report the elements of the review that are directly relevant to the aims of this thesis.

Overview of Included Studies

The scoping review identified a growing body of empirical research on HRC in healthcare. Following the search conducted on 2 December 2023, 74 journal articles published between 2006 and 2023 met the inclusion criteria, with a pronounced increase in recent years: 50 studies (over 67%) were published between 2021 and 2023. Publications were concentrated in engineering- and robotics-oriented journals, including *Sensors* (7 articles), and *IEEE Robotics and Automation Letters* (6), with comparatively few appearing in clinical outlets such as the *Journal of NeuroEngineering and Rehabilitation* (2). The reviewed literature shows broad international participation, led by China (16 publications), followed by the United States (9), Italy (6), and Germany (6).

Clinical Domains and Application Areas

To characterise the scope of HRC applications represented in the reviewed literature, the included studies were grouped according to their primary clinical domain or application area. The distribution of studies across these categories is illustrated in Figure 2.1.

The empirical literature is unevenly distributed across clinical domains, with a strong concentration in a small number of application areas.

Robot-Assisted Surgery Robot-assisted surgery represents the largest application category, comprising 29 studies (approximately 39% of the dataset). These studies examine collaborative robotic systems supporting surgical procedures across a range of specialities, including general surgery (Bowyer and Rodriguez Y Baena 2014; Hu et al. 2023), laparoscopic surgery (Fontúrbel et al. 2023; Lecointre et al. 2022; Sandoval et al. 2021), dental implant surgery (Kan et al. 2022; Qiao et al. 2023; Riva et al. 2022), spine surgery (Koszulinski et al. 2022), middle ear surgery (So et al. 2022; Lim et al. 2016), craniotomy (Xu et al. 2021; Xia et al. 2023),

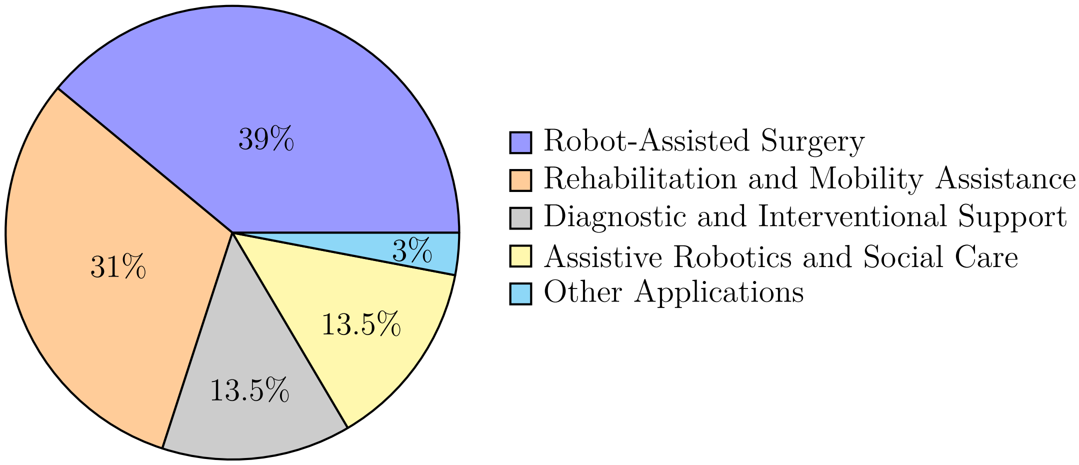

Figure 2.1: Distribution of robotics applications in healthcare

gynaecological surgery (Yip et al. 2020), and hair transplantation (Erdogan et al. 2020).

Across these studies, collaboration is primarily framed in terms of precision, accuracy, and task execution (e.g., Bowyer and Rodriguez Y Baena 2014; Lecointre et al. 2022; Kan et al. 2022; Riva et al. 2022; Erdogan et al. 2020), alongside safety and control mechanisms(e.g., Fontúrbel et al. 2023; Lehmann et al. 2018). Several studies also report on the effects of robotic collaboration on surgeon workload and ergonomics (e.g., Yang et al. 2022; Tucan et al. 2022).

Physical Rehabilitation and Mobility Assistance Physical rehabilitation and mobility assistance constitute the second largest category, with 23 studies (approximately 31%). These studies focus on collaborative robotic systems designed to support patients with motor impairments or those undergoing rehabilitation. Applications include lower-limb rehabilitation and gait training (Dionisio and Brown 2016; Wolański et al. 2023), upper-limb rehabilitation (Brahmi et al. 2021, 2019; Chiriatti et al. 2022; Qu et al. 2021), assistive mobility devices (Galluppi et al. 2009; Xu et al. 2014; Sunny et al. 2021), and tele-rehabilitation systems (Mocan et al. 2022; Johnson et al. 2008).

Several studies in this category integrate complementary technologies—such as virtual reality (Mocan et al. 2022), brain–computer interfaces (Quiles et al. 2022), and eye-gaze control (Sunny et al. 2021)—to enhance collaborative interaction between users and robotic systems.

Diagnostic and Interventional Support Diagnostic and interventional applications account for 10 studies (approximately 13.5%). These include collaborative robotic systems used in medical imaging (Ipsen et al. 2021; Wang et al. 2023; Xing et al. 2023; Vitrani et al. 2015; Li et al. 2020; Bader et al. 2021) and the automation or support of microbiology laboratory workflows (Jung et al. 2023; Deniz and Gökmen 2021; Parak and Juricek 2022; Baumkircher et al. 2022). In these studies, collaboration is often framed around task assistance, positioning, or workflow optimisation rather than continuous human–robot interaction.

Assistive Robotics and Social Care Assistive robotics and social care applications also comprise 10 studies (approximately 13.5%). These systems are designed to support daily living activities, care provision, or social interaction, particularly for older adults or individuals with disabilities. Applications include robotic support for nursing staff (Colucci et al. 2021; Freeman et al. 2021; Kowalski et al. 2020; Li et al. 2023) and assistive or socially interactive robots for eldercare and dementia care (Klebbe et al. 2022; Gutman et al. 2023; Lv et al. 2020).

Other Applications A small number of studies (approximately 3%) fall outside the main categories and address niche applications of HRC in healthcare-related contexts. These include telerobotic systems for telemedicine and space medicine (Haidegger et al. 2012), as well as collaborative mobile robots used in biomanufacturing and bioprocessing environments (Mathew et al. 2022).

Study Settings and Research Environments

The setting of an HRC study directly shapes the relevance and transferability of its findings. To characterise evaluation contexts in the reviewed literature, studies were grouped into five categories based on their primary research setting, as shown in Figure 2.2.

- **Controlled laboratory environments**: About 54% of the studies took place in controlled, non-clinical labs.
- **Actual clinical environments**: Nearly 19% were conducted in real healthcare facilities such as hospitals and rehabilitation centres.
- **Unspecified environments**: Around 15% of the papers did not clearly define the research setting. These studies often focused primarily on system design or technical evaluation, with limited attention to contextual features of deployment.
- **Simulated healthcare environments**: About 9% used simulations that

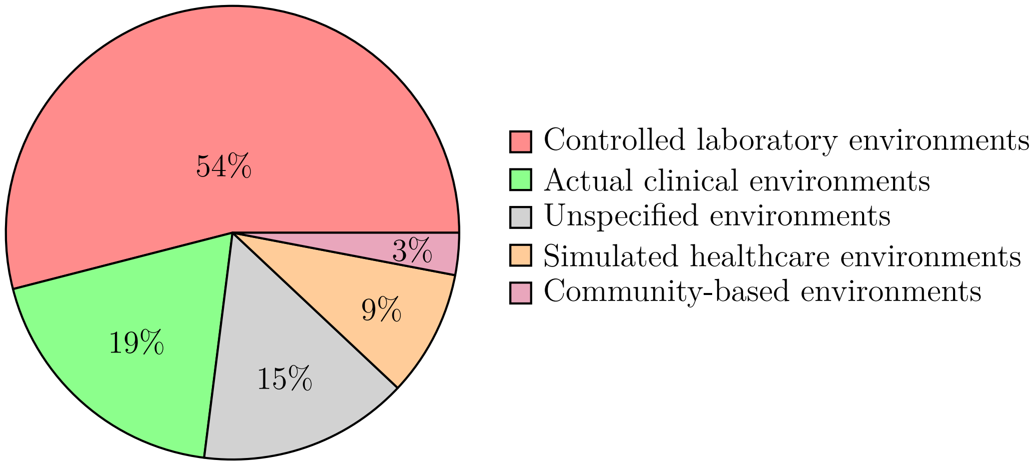

Figure 2.2: Distribution of study settings in empirical HRC healthcare research

combine realism with experimental control. These are often useful for early-stage testing before real-world deployment.

- **Community-based environments**: A small number of studies took place in settings like aged care homes or community centres.

Overall, the reviewed literature shows a strong reliance on controlled laboratory environments for the empirical evaluation of HRC systems in healthcare, with more than half of the studies conducted outside real clinical contexts. This reflects the practical and ethical challenges associated with deploying experimental robotic systems in healthcare settings, particularly where patient safety and institutional constraints are involved. While laboratory and simulated environments allow for controlled testing of interaction mechanisms, safety strategies, and task performance, they offer limited exposure to the complexities of real-world clinical workflows. The smaller proportion of studies conducted in actual clinical and community-based environments suggests that empirical HRC research in healthcare remains largely at an early or intermediate stage of translation, with relatively few systems evaluated under routine care conditions.

2.2.1 Dominant Research Themes

To further characterise the empirical landscape of HRC in healthcare, the reviewed studies were analysed according to their primary research focus. This categorisation captures the main aspects of HRC that each study emphasised, recognising that many papers address multiple themes but typically prioritise one. Table 2.1 summarises the distribution of studies across these focus areas.

The empirical literature is strongly oriented towards technical and system-level con-

Table 2.1: Categories of research focus areas

Category	Count
Design and Development (Robot, System, or Application)	31
Human-Robot Interaction and Control	22
Technical Improvement	13
Patient Experience and Acceptance	3
Feasibility, Implementation and Integration	2
Ethical, Social, and Legal Concerns	2

cerns. Most studies focus on the design and development of robotic platforms or applications, as well as on interaction mechanisms and control strategies that enable safe and effective collaboration between humans and robots. A further subset emphasises incremental technical improvements, such as enhancements in sensing, control accuracy, or autonomy. In contrast, relatively few studies explicitly foreground patient experience, acceptance, or broader implementation considerations, including organisational integration and ethical or legal implications. This distribution suggests that empirical HRC research in healthcare has largely prioritised technological feasibility and performance, with comparatively limited attention to downstream factors that influence real-world adoption and sustained use in clinical and care settings.

2.2.2 Identified Research Gaps

The scoping review highlights several limitations in the existing empirical literature on HRC in healthcare. While the field is expanding rapidly, the current body of work remains uneven in both its thematic emphasis and its methodological maturity. Multiple potential gaps can be identified, including conceptual ambiguity surrounding HRC, limited longitudinal evaluation, inconsistent outcome measures, and a strong reliance on engineering-led research perspectives. From these, three interrelated gaps are particularly salient for the aims of this research and are therefore prioritised in this thesis.

Limited attention to human, ethical, organisational, and social factors First, the empirical literature demonstrates a pronounced emphasis on technical feasibility, system design, and control performance, with comparatively little attention given to the human, ethical, organisational, and social dimensions of HRC. As shown in Table 2.1, only a small number of studies explicitly address patient experience and acceptance, feasibility and integration into care workflows, or ethical, social, and legal considerations. While many studies implicitly involve human actors, humans are often treated primarily as system operators or sources of performance variability rather than as stakeholders embedded in complex clinical environments.

Narrow clinical focus dominated by surgery and rehabilitation Second, the reviewed literature exhibits a narrow concentration on a limited set of clinical domains. Robot-assisted surgery and physical rehabilitation together account for the majority of empirical HRC studies, as illustrated in Figure 2.1. While these areas are well suited to controlled experimentation and benefit from clear task structures, they represent only a subset of healthcare activities where HRC may be relevant. Other healthcare contexts — such as nursing care, diagnostics, ward logistics, long-term care, intensive care, and mental health support — are comparatively under-represented. This narrow focus constrains the generalisability of existing findings and risks shaping HRC concepts primarily around contexts that privilege controllability and repeatability, thereby marginalising forms of care work that are adaptive, collaborative, and deeply contextual. Expanding empirical attention to a wider range of clinical settings is therefore necessary to develop a more comprehensive and transferable understanding of HRC in healthcare.

Limited ecological validity Third, and closely related, empirical evaluations of HRC systems are predominantly conducted in controlled laboratory or simulated environments. As shown in Figure 2.2, more than half of the reviewed studies take place outside actual clinical contexts, with fewer than one fifth conducted in real healthcare environments. While laboratory-based studies are valuable for early-stage development and safety validation, they offer limited ecological validity and therefore provide only partial insight into how HRC systems interact with real clinical workflows, organisational constraints, and contextual pressures. This concern reflects a broader critique within the field of human–robot interaction regarding the lack of ecologically valid approaches in experimental design (Busby Grant and Herath 2022).

Importantly, patterns of human interaction and collaboration with robotic systems may differ substantially between controlled laboratory settings and real-world healthcare environments, where time pressure, interruptions, social dynamics, and patient-related contingencies shape practice (Andriella et al. 2025). The scarcity of *in-situ* evaluations consequently restricts understanding of how HRC systems are integrated into everyday care practices, how clinicians adapt their work around them, and how unanticipated challenges emerge over time. This gap points to a broader translational challenge in the field, where promising technical systems remain insufficiently tested under routine conditions. Addressing this limitation requires empirical research that engages directly with real-world healthcare settings and captures the situated and dynamic nature of HRC in practice.

2.2.3 Summary and Implications of the Scoping Review

Taken together, the scoping review demonstrates that empirical research on HRC in healthcare has made substantial progress in establishing technical feasibility across a range of clinical domains. At the same time, the review reveals limited sustained engagement with the broader conditions under which HRC can be meaningfully integrated into clinical practice. While these issues surface intermittently across the reviewed studies, they are rarely treated as primary objects of analysis, limiting the capacity of the HRC literature to account for the conditions under which collaboration can be sustained beyond experimental settings.

2.3 Sociotechnical Systems

Building on the preceding review, in this section, I introduce STS theory as the primary analytical lens for examining how HRC is shaped by the interaction of technological, human, and organisational factors. Here, I refer to STS in its classic tradition, which examines how social and technical elements relate to and shape one another through their interactions and interdependencies.

2.3.1 Background and Core Principles

STS thinking emerged from post-war studies of industrial work, most notably the Tavistock Institute's research on coal mining in the United Kingdom by scholars such as Trist, Bamforth, Emery, and others (Trist and Bamforth 1951; Trist 1981). Early STS work argued that work systems comprise interacting subsystems — a *technical* subsystem (tools, processes, equipment, task constraints) and a *social* subsystem (roles, skills, relationships, norms, and coordination structures) — and that system outcomes depend on how these subsystems are configured together (Trist 1981; Mumford 2000; Pasmore et al. 1986). A central implication is that the same technology can produce very different outcomes depending on how responsibilities, workflows, and coordination are organised around it.

While STS is not a single unified theory, the literature converges on several foundational commitments about how work systems function. First, organisational systems are treated as *open systems*: they comprise interdependent parts, pursue goals in an external environment, and contain distinct yet interdependent social and technical elements(Baxter and Sommerville 2011). From an STS perspective, system performance depends on the *joint optimisation* of social and technical subsystems rather than the optimisation of either in isolation (Baxter and Sommerville 2011).

Another commitment is that work systems are dynamic, with technologies being adapted in use, workarounds emerging through practice, and both technical arrangements and organisational policies evolving over time (Cherns 1987; Baxter and Sommerville 2011; Holden et al. 2013). Accordingly, STS-informed design tends to prioritise iterative development, learning from use, and ongoing adjustment rather than one-off “implementation” (Carayon 2006; Clegg 2000; Holden et al. 2013).

These commitments have been expressed as widely used design heuristics. In Cherns’s classic formulation, for example, effective socio-technical design should (i) align design choices with the system’s purpose, (ii) specify only what must be standardised while leaving room for local adaptation, (iii) handle problems as close as possible to where they arise, (iv) support flexible roles and coordination, (v) ensure that information reaches the people who need it in order to act, (vi) provide support (e.g., training and resources) that matches the demands created by the new system, (vii) keep human values in view, and (viii) treat design as iterative because work systems evolve over time (Cherns 1976, 1987; Mumford 2000). Building on Cherns, Clegg proposes an extended set of sociotechnical principles organised as *meta-*, *content-*, and *process-* principles, reflecting the systemic, value-laden, and politically situated nature of design in complex organisations (Clegg 2000). Notably, this tradition is tightly coupled to participatory and human-centred design approaches, which is particularly relevant for healthcare contexts.

2.3.2 Sociotechnical Approaches in Healthcare

STS gained prominence in healthcare alongside the growth of health information technology and patient safety research (Kemp et al. 2024; Carayon 2006). Several widely used frameworks illustrate how STS has been operationalised in healthcare and provide complementary ways to analyse implementation and outcomes.

A prominent example is the Systems Engineering Initiative for Patient Safety (SEIPS) framework (Carayon et al. 2006). SEIPS conceptualises care delivery as a work system comprised of interacting elements (e.g., people, tasks, tools and technologies, the physical environment, and organisational conditions) that shape care processes and, in turn, patient and worker outcomes (Figure 2.3). Later iterations (SEIPS 2.0 and 3.0) place greater emphasis on system dynamics, adaptation, and

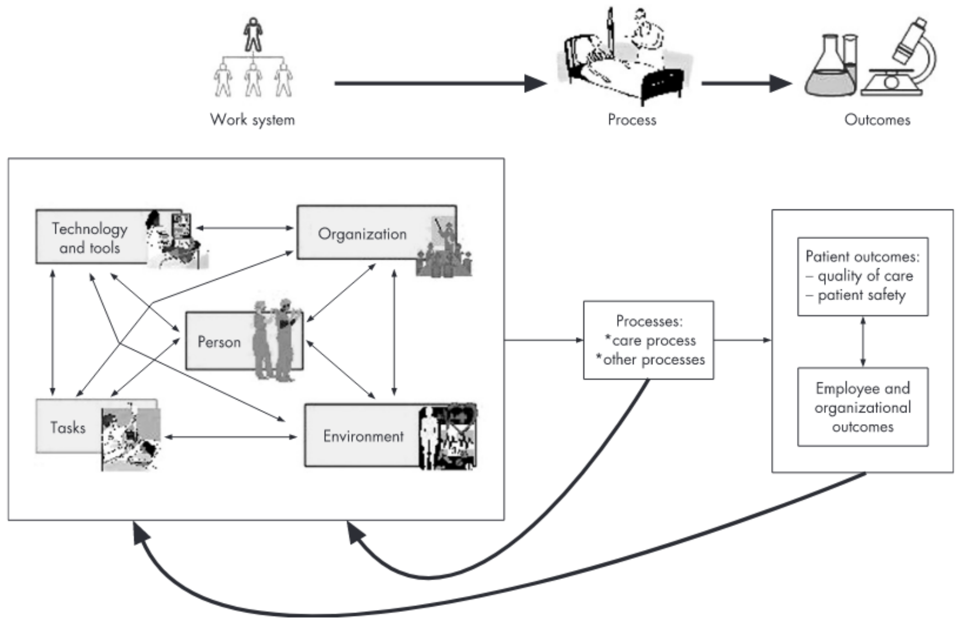

Figure 2.3: SEIPS model of work system and patient safety (Carayon et al. 2006).

the co-evolution of work practices and technologies (Holden et al. 2013; Carayon et al. 2020).

A second influential framework is Sittig and Singh's eight-dimensional sociotechnical model, developed to guide safe and effective implementation of health information technology (Sittig and Singh 2010). Rather than treating technology as a standalone artefact, the model spans technical infrastructure, clinical content, human-computer interfaces, users and roles, workflow and communication, internal organisational context (including policies and culture), external constraints (such as rules and regulations), and ongoing measurement and monitoring (Figure 2.4). In practice, the model is often used to structure implementation planning and anticipate safety risks that can arise when changes in one dimension (e.g., interface design) interact with others (e.g., workflow, staffing, training, or governance).

Where SEIPS and Sittig-Singh are frequently applied to understand and improve systems in use, the NASSS framework (Nonadoption, Abandonment, and challenges to the Scale up, Spread, and Sustainability) provides a complementary account of why healthcare technologies succeed or fail beyond initial adoption (Greenhalgh et al. 2017). NASSS analyses seven interacting domains — the condition, the technology, the value proposition, adopters, the organisation, the wider system, and embedding/adaptation over time (Figure 2.5) — and is especially useful for characterising complexity and uncertainty across the technology lifecycle. In particular, NASSS helps explain why apparently successful pilots may struggle when scaled,

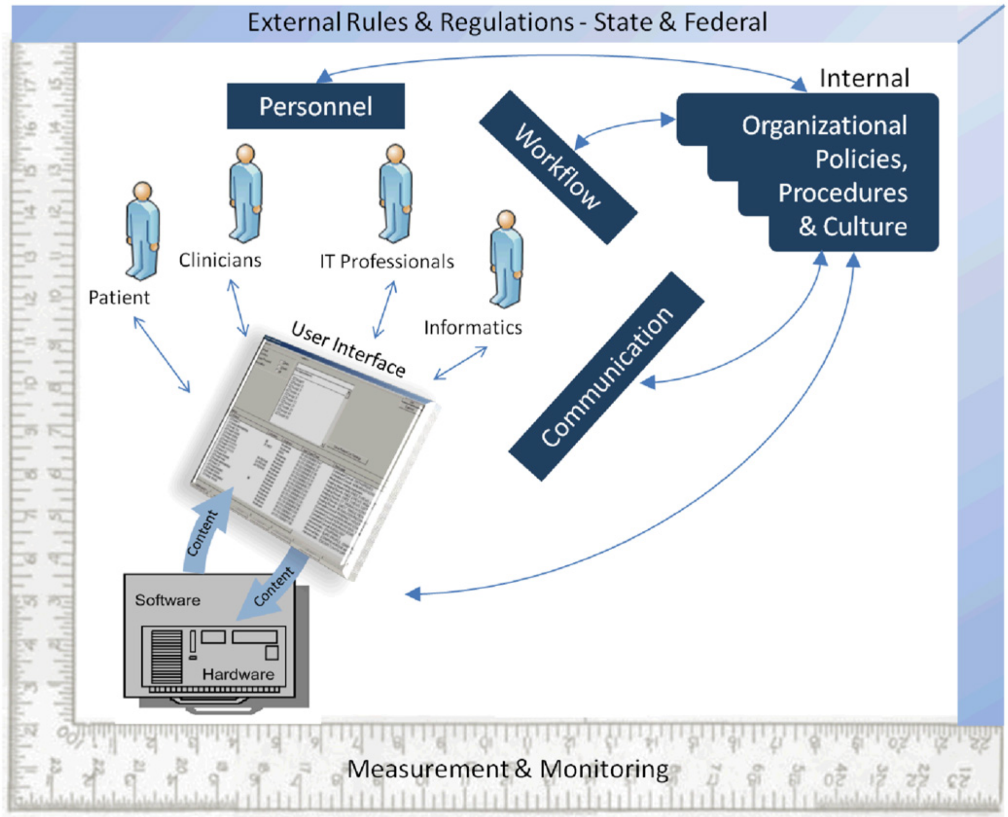

Figure 2.4: Sittig and Singh's eight-dimensional sociotechnical model (Sittig and Singh 2010).

transferred across contexts, or sustained over long periods, as technologies must be continually embedded, adapted, and supported amid shifting organisational and system-level constraints.

Although these frameworks overlap conceptually, they differ in their primary unit of analysis and time horizon. SEIPS is commonly used to analyse or redesign local work systems and link work-system conditions to processes and outcomes. The Sittig and Singh model foregrounds the multiple sociotechnical dimensions that must be addressed to implement and manage health information technology safely, with particular utility for risk management and governance. NASSS focuses on lifecycle dynamics and long-term embedding, scale-up, spread, and sustainability.

Recent work extends healthcare STS to the distinctive challenges of AI. For example, Salwei and Carayon extend SEIPS to the context of AI implementation, emphasising alignment with workflows, temporal demands, and user needs for transparency and trust (Salwei and Carayon 2022). McCradden et al. argue for treating AI tools as part of an "intervention ensemble" — a constellation of practices, oversight mechanisms, and contextual conditions required to produce patient benefit — shift-

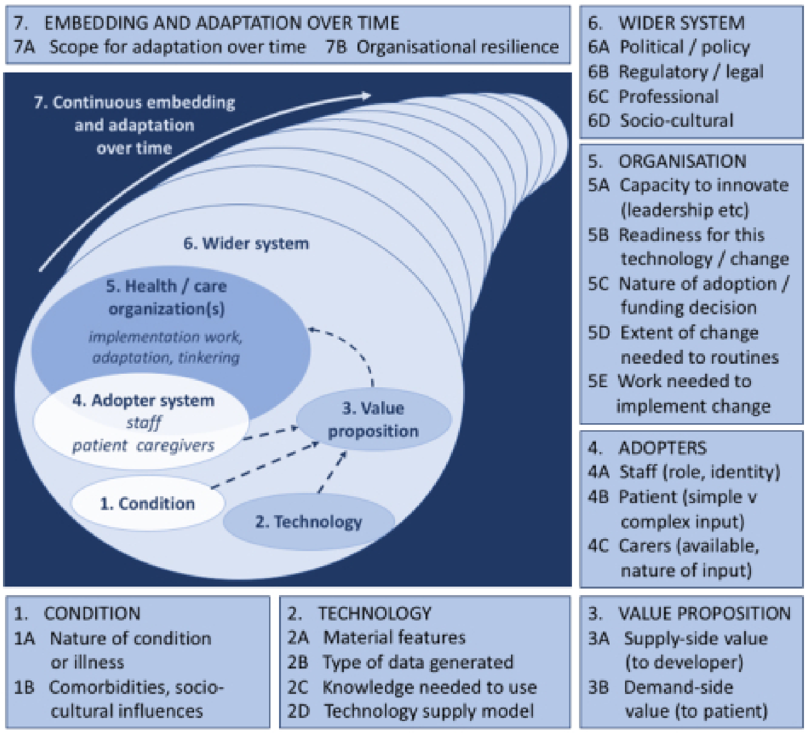

Figure 2.5: The NASSS framework (Greenhalgh et al. 2017).

ing evaluation beyond the algorithm toward the sociotechnical configuration of use (McCradden et al. 2023).

Complementing these STS-informed approaches, implementation frameworks drawing on implementation science have been suggested to provide additional structure for operational planning, governance, and ongoing evaluation. For example Consolidated Framework for Implementation Research (CFIR) (Breimaier et al. 2015) and the RE-AIM (Reach, Effectiveness, Adoption, Implementation and Maintenance) framework (Holtrop et al. 2021) offer taxonomies of constructs that can be used to anticipate barriers and facilitators and to measure implementation outcomes.

Another way of extending these sociotechnical perspectives is to engage with research on technology acceptance. Whereas STS-informed frameworks foreground the wider configuration of people, practices, organisations, and infrastructures, acceptance models focus more specifically on the perceptions and intentions that shape whether technologies are adopted and used. Examining both perspectives together offers a more complete account of technological change in healthcare.

2.3.3 Technology Acceptance Models

Technology acceptance models offer a well-established way to examine why people do or do not intend to use a technology and how use is sustained over time. Although they are not sociotechnical theories in the classic STS sense, they remain highly relevant in healthcare because stakeholder acceptance is widely recognised as a prerequisite for the adoption and implementation of new systems in routine practice (Sekhon et al. 2017; Gagnon et al. 2012; Madi et al. 2024). These models primarily explain technology use through individual perceptions such as perceived usefulness, perceived ease of use, and social influence. However, such perceptions are not formed in isolation. In healthcare, they are shaped by sociotechnical conditions of implementation, including workflow fit, role allocation and accountability, safety practices, training and support, and the institutional legitimacy of the technology. In this sense, acceptance models can be understood as a *measurement-level complement* to STS analysis. They provide a structured vocabulary for stakeholder perceptions, while sociotechnical approaches help explain how those perceptions are produced by the wider configuration of practice.

The Technology Acceptance Model (TAM) (Davis 1989) and the Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al. 2003) are two dominant frameworks. In healthcare acceptance research, reviews consistently show that TAM and UTAUT are the most frequently applied approaches (AlQudah et al. 2021; Ammenwerth 2019; Holden and Karsh 2010). TAM proposes that two core perceptions — perceived usefulness and perceived ease of use — determine an individual's behavioural intention to use a technology (Davis 1989). Perceived usefulness refers to the degree to which a person believes that a system enhances job performance, while perceived ease of use refers to the degree to which the system is perceived as free of effort. Behavioural intention, in turn, is assumed to predict actual use. UTAUT incorporates determinants that extend beyond individual cognition (e.g., social influence and facilitating conditions) (Venkatesh et al. 2003). In UTAUT, behavioural intention is primarily shaped by *performance expectancy*, *effort expectancy*, and *social influence*, while *facilitating conditions* and behavioural intention jointly shape use (Figure 2.6). Importantly, UTAUT's inclusion of facilitating conditions provides an explicit bridge to STS concerns, because it captures whether organisational and technical infrastructures (e.g., training, support, interoperability, staffing, time, and policies) enable use rather than treating adoption as a matter of individual preference alone.

For healthcare robotics, TAM and UTAUT continue to serve as the predominant

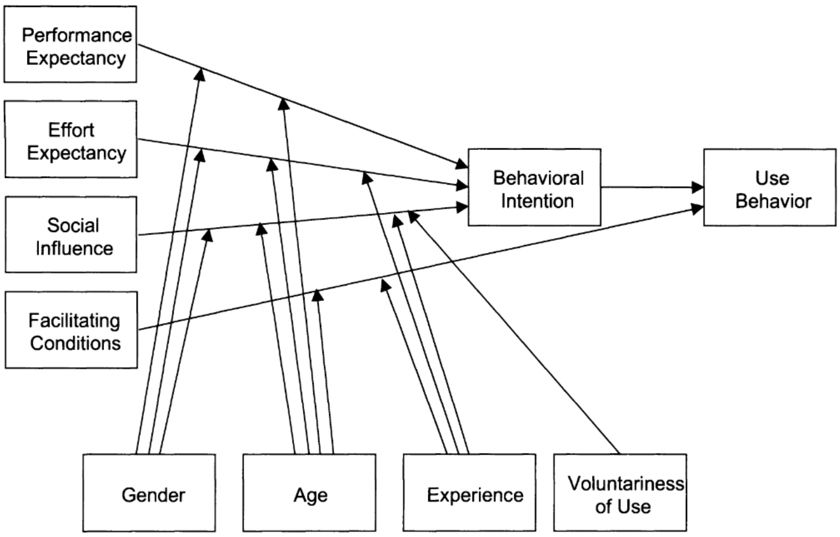

Figure 2.6: Schematic representation of the UTAUT model (adapted from Venkatesh et al. 2003).

frameworks for assessing acceptance and its determinants (David et al. 2022). Model extensions have been used across diverse care settings, such as nursing assistance (Saadatzi et al. 2020; Vichitkraivin and Naenna 2021), COVID-19 related tasks (Bakshi et al. 2022), hospital pharmacy (Hogan et al. 2020), rehabilitation (Luciani et al. 2023), assistive exoskeletons (Chen et al. 2023), home care robots (Alaiad et al. 2013; Yeoh and Chin 2022; Chen 2018), socially assistive robots (Beuscher et al. 2017), psychological practice (Conti et al. 2015), dementia care (Wasić et al. 2022), and robot-assisted surgery (Darwish et al. 2023). In care robotics, these extensions commonly incorporate constructs including perceived sociability, anxiety, attitudes towards technology, user experience, and robot functionality (David et al. 2022).

Overall, these studies indicate that the acceptance of healthcare technologies is shaped by a multitude of factors. Although established acceptance models such as TAM and UTAUT are often used as foundational frameworks, additional constructs are incorporated to suit specific contexts and to address the unique demands and innovative nature of these studies (Ammenwerth 2019). David et al. highlight that the original frameworks do not fully account for the complexity of some emerging technologies, especially those with interactive, social, or anthropomorphic features (David et al. 2022). Consequently, robust and standardised tools for evaluating the acceptability of such robots remain limited.

In healthcare robotics, TAM- and UTAUT-based studies are widely used to examine determinants of adoption and use, but they are frequently extended with constructs such as trust, perceived safety, anxiety, and robot-related attitudes (Saadatzi et al. 2020; Vichitkraivin and Naenna 2021; David et al. 2022). Such extensions are especially pertinent for HRC, where adoption judgements are often grounded in assessments of safety and predictability during interaction, clarity of accountability when things go wrong, and the perceived alignment of robotic capabilities with professional roles and the values of care.

2.4 Barriers and Facilitators of Healthcare Robotics

The preceding discussion has shown that STS and technology acceptance models offer complementary ways of understanding technology use in healthcare: STS highlights the wider configuration of social, organisational, and technical elements, while acceptance models focus more specifically on stakeholder perceptions and intentions. To move from these conceptual perspectives to the empirical concerns of this thesis, this section reviews the broader healthcare robotics literature on barriers and facilitators to implementation, integration, and adoption. Because the HRC-specific evidence base remains relatively limited in its treatment of implementation and uptake, and because HRC is a subset of healthcare robotics that shares many implementation conditions (as shown in Section 2.2), the broader robotics literature provides a provisional but relevant evidence base for identifying the sociotechnical determinants likely to shape HRC integration in practice.

Across this healthcare robotics literature, barriers and facilitators are most often reported as lists of factors associated with use, integration, deployment, adoption, implementation, or acceptance. The studies synthesised here cover a range of care contexts.

- **Studies on long-term and residential aged care, including dementia care** (Wong et al. 2023; Koh et al. 2022; Herath et al. 2023; Hung et al. 2019; Fernandes et al. 2025; Luo et al. 2024; Rigaud et al. 2024; Wong et al. 2024; Servaty et al. 2020; Melkas et al. 2020; Wasic et al. 2024)
- **Studies on hospital and in-patient settings** (Klebbe and Friese 2025; Brünett et al. 2025; Ohneberg et al. 2025; Rasmussen et al. 2024; Gumus and Alan 2025; Vallès-Peris et al. 2021)
- **A study on mental health settings** (Guemghar et al. 2022)
- **Cross-setting studies on implementation, data, and governance**

across clinical domains (Cresswell et al. 2018; Elendu et al. 2023; Denecke and Baudoin 2022)

To guide the discussion that follows, the subsections below organise the literature across micro–meso–macro levels of analysis. Aligned with the sociotechnical stance of this research, organising the review in this way makes it possible to show how barriers and facilitators arise at different levels. This multilevel structure is intended to support the sociotechnical analysis developed in this thesis.

This synthesis does not aim to provide an exhaustive catalogue of all reported barriers and facilitators, nor does it seek to impose a rigid taxonomy on a diverse body of literature. Rather, it uses the micro–meso–macro structure as an analytic device for organising recurring issues in ways that are useful for interpretation in upcoming chapters, while recognising that many determinants cut across levels and remain contingent on context.

2.4.1 Micro-level: Individual and Interactional

At the micro level, barriers and facilitators relate to how individuals (patients, healthcare professionals, residents, family members, and staff) perceive robots, develop expectations of them, and experience interaction during care. These factors include perceived usefulness, emotional responses, trust, comfort and dignity, usability, and how robotic interactions align (or clash) with the relational character of care work.

A prominent micro-level barrier concerns *value and identity tensions*: robots may be interpreted as misaligned with what "good care" requires, particularly when care is understood as inherently relational. In long-term care implementations, staff described misalignment between robotic use and professional values, alongside concerns that technology-mediated encounters could undermine care quality or dignity (Wong et al. 2023). Similar issues are expressed in inpatient and cross-setting work, where ethical concerns cluster around dehumanisation, deception (e.g., misleading users about a robot's capacities), and the risk that efficiency narratives overshadow empathy (Rigaud et al. 2024; Brünett et al. 2025; Cresswell et al. 2018). Patient-facing robots also raise interactional worries about reduced interpersonal contact and loss of "human touch" in care encounters (Klebbe and Friese 2025; Vallès-Peris et al. 2021; Gumus and Alan 2025). Importantly, these concerns are not merely attitudes to technology in the abstract; they are situated judgments about how robotics re-shapes care relationships.

A second cluster relates to *readiness, familiarity, and experiential confidence.* Across studies, limited exposure to robots constrains acceptance: where patients or staff have few opportunities to interact with robots, uncertainty and scepticism persist (Cresswell et al. 2018; Klebbe and Friese 2025). In residential contexts, “readiness mismatches” occur when robots are introduced without sufficient consideration of residents’ cognitive, sensory, or emotional needs, producing distress or disengagement for some users (Wong et al. 2023; Rigaud et al. 2024). These findings underscore that micro-level acceptance is partly an implementation outcome: confidence grows when interactions are scaffolded through time, practice, and supportive social environments (Wong et al. 2023; Melkas et al. 2020).

Interactional barriers also emerge from *usability, adaptability, and communication quality.* Studies emphasise that robots must be easy to operate within real care routines, with interfaces and behaviours that accommodate diverse abilities (Rigaud et al. 2024; Rasmussen et al. 2024). In wearable robotics with older adults, comfort, discreet design, and fit with users’ embodied preferences are described as enabling conditions for use (Reicherzer et al. 2024). In addition, interaction can break down when communication channels are limited; conversely, multimodal communication (e.g., projection, text-to-speech) can support engagement and comprehension in patient-facing scenarios (Wasic et al. 2024). Where robots require high attention, frequent troubleshooting, or complex set-up, perceived complexity becomes an immediate barrier to sustained use (Wong et al. 2023; Ohneberg et al. 2025).

Micro-level facilitators are often framed in terms of *perceived benefits to users and care relationships.* Telepresence was valued when it met residents’ and families’ needs for connection, particularly under conditions of restricted visitation, and when it supported meaningful, private communication (Wong et al. 2023). In dementia and older adult care, social and pet robots are associated with psychosocial benefits such as improved mood, reduced agitation, and enhanced engagement, which can motivate staff to integrate them into care (Hung et al. 2019; Koh et al. 2022; Fernandes et al. 2025). In mental health contexts, reported outcomes similarly position social robots as potentially supportive of therapeutic engagement, while also highlighting the need to manage expectations and ensure clinically appropriate use (Guemghar et al. 2022). Overall, micro-level facilitators are strongest when benefits are legible to both users and staff and are experienced as enhancing relational care (Hung et al. 2019; Brünett et al. 2025).

2.4.2 Meso-level: Organisational and Institutional

At the meso level, barriers and facilitators concern organisational conditions that shape whether robotics can be integrated into work systems: workflows, roles, staffing and resources, training arrangements, maintenance and support structures, and the institutional logics (e.g., priorities, performance metrics, safety culture) through which robotics is evaluated.

A dominant meso-level barrier is *workflow disruption*. Robots frequently introduce new tasks (preparation, cleaning, charging, transporting, troubleshooting), and these tasks can be experienced as additive rather than substitutive, especially in settings already facing time pressure (Rigaud et al. 2024; Wong et al. 2024; Ohneberg et al. 2025; Klebbe and Friese 2025). This is analytically important: many studies describe "workload reduction" as a promised benefit, yet early-stage implementation often produces a temporary (or persistent) workload increase when routines, responsibilities, and contingencies are not explicitly redesigned (Melkas et al. 2020; Rasmussen et al. 2024). In this sense, workload effects are not properties of robots alone but emergent outcomes of organisational fit.

Relatedly, *role clarity and responsibility allocation* are repeatedly highlighted. In an aged care case study of a logistics robot, the absence of detailed end-to-end role mapping generated uncertainty about task allocation, responsibility boundaries, and how robot-related activities would be integrated into existing work practices, contributing to organisational friction (Herath et al. 2023). Cross-setting work similarly notes that unclear responsibilities and institutional ambiguity can impede safe deployment, particularly when robots cross boundaries between clinical and operational domains (Cresswell et al. 2018; Denecke and Baudoin 2022).

Resource and capacity constraints are also central. Meso-level barriers include limited staff training, lack of time to practise, and insufficient organisational support for implementation activities (Hung et al. 2019; Luo et al. 2024; Rasmussen et al. 2024; Wong et al. 2024). Importantly, training is not only a skills issue but an organisational commitment: when training is accessible and embedded in routines, staff report increased self-efficacy and confidence, which in turn supports robotics uptake (Wong et al. 2023). *Built environments* play a central role as well. Herath et al. illustrate how space and corridor safety, along with the need for architectural modifications or workarounds, fundamentally condition the success of robotic deployment in care settings (2023).

Meso-level facilitators tend to describe *integration and implementation as collective work*. Leadership engagement and organisational goal alignment are repeatedly reported as enabling conditions, particularly when robotics is tied to clearly articulated service problems rather than introduced as novelty (Wong et al. 2023; Melkas et al. 2020). In long-term care, supportive engagement and open communication spaces help surface issues early and normalise learning, reducing the likelihood that early failures become entrenched as negative organisational narratives (Wong et al. 2023). This aligns with findings that staff attitudes are shaped not only by robot capabilities but by whether organisations create psychologically safe conditions for experimentation and feedback (Brünett et al. 2025; Rasmussen et al. 2024).

2.4.3 Macro-level: Systemic and Societal

At the macro level, barriers and facilitators concern system-wide conditions that shape what organisations can procure, legitimise, and sustain: funding and reimbursement, regulation and liability, standards and governance, and societal debates about ethics, safety, and the future of care work.

A recurring macro barrier is *economic feasibility*, including acquisition costs, maintenance burdens, and uncertain returns on investment. In long-term care and geriatric contexts, high costs and constrained funding streams limit adoption, particularly when benefits are diffuse, long-term, or difficult to translate into existing accounting categories (Koh et al. 2022; Rigaud et al. 2024; Servaty et al. 2020). Unclear reimbursement pathways further weaken the business case for organisations, even when frontline benefits are plausible (Servaty et al. 2020; Reicherzer et al. 2024). These studies suggest that cost is not only a budget line item but also a governance issue: without reimbursement and funding models that recognise the benefits, robotics remains structurally disadvantaged relative to interventions with clearer payment pathways (Servaty et al. 2020; Denecke and Baudoin 2022).

A second macro-level barrier concerns *regulation, compliance, and accountability.* Infection prevention requirements, safety standards, and compliance obligations are some of the factors that can shape which robots can be deployed and how they must be maintained (Koh et al. 2022; Herath et al. 2023). Cross-setting analyses emphasise broader ethical and legal gaps, including uncertainty about responsibility when harms occur, ambiguity in accountability chains, and the need for robust governance around safety and security (Cresswell et al. 2018; Denecke and Baudoin 2022; Elendu et al. 2023). These are not abstract concerns: they influence procurement decisions, risk tolerance, and the legitimacy of robotics within public-facing healthcare systems (Cresswell et al. 2018; Elendu et al. 2023).

Macro-level debates also include *societal acceptability and the politics of care.* Studies point to resistance rooted in concerns about technology substituting for human labour, altering professional roles, or amplifying inequities in access and quality (Denecke and Baudoin 2022; Elendu et al. 2023; Rasmussen et al. 2024). Patient-facing perspectives similarly foreground worries about diminished human contact and the moral meaning of receiving care from machines (Vallès-Peris et al. 2021; Gumus and Alan 2025). In this sense, macro-level conditions shape micro-level interactions: public narratives about automation, privacy, and dignity can prefigure how robots are interpreted when they arrive in clinical spaces (Elendu et al. 2023; Denecke and Baudoin 2022).

Macro-level facilitators are typically described as *enabling infrastructures of legitimacy*: funding mechanisms (e.g., grants), clear regulatory pathways, and evolving ethical guidance. In the aged care logistics case study, external financial support reduced adoption friction and helped justify investment (Herath et al. 2023). Reviews and ethics-oriented work argue for clearer assignment of responsibilities, updated healthcare-specific ethical guidelines, and regulatory frameworks that classify risks and standardise assurance requirements (Elendu et al. 2023; Denecke and Baudoin 2022; Cresswell et al. 2018). At the system level, such developments matter because they reduce uncertainty for organisations and vendors, support comparability across products, and provide a shared language for evaluating safety, privacy, and accountability.

2.5 Sociotechnical Framing For HRC in Healthcare

This chapter positioned HRC within a longer tradition of human–machine partnership and then examined its use in healthcare through a scoping review (Section 2.2). The review identified a fast-growing but uneven evidence base, with most studies evaluating HRC systems mainly in laboratory or simulated settings. To move beyond technical feasibility, the chapter synthesised barriers and facilitators across micro–meso–macro levels, showing that adoption depends on perceived value and relational fit, integration into routines and roles, and enabling infrastructures such as training, governance, regulation, and funding. Finally, it introduced sociotechnical systems theory and complementary acceptance models as the analytical lenses used in this thesis to examine how HRC is configured, embedded, and sustained in real clinical practice.

The barriers and facilitators in Section 2.4 make it clear that healthcare robotics, and in particular HRC, raises a distinctly sociotechnical problem due to organisational, professional, ethical, and regulatory conditions of care delivery. Sociotechnical frameworks and approaches are therefore well-suited to this domain because they provide concepts and structures for analysing how robotics systems becomes embedded in practice.

However, despite the maturity of STS-informed frameworks in healthcare, there are comparatively few sociotechnical frameworks developed *specifically* for robots in healthcare. Existing work more often adapts general STS approaches or develops domain-specific tools that address sociotechnical concerns indirectly. One example is the "READY?" reflective dialogue tool, designed to support institutional deliberation about robotics in nursing care across multiple categories including care practices, privacy and legal issues, ethics, infrastructure, institutional embeddedness, and economics (Lienenbrink et al. 2025). While not framed as a full sociotechnical theory, READY? operationalises a multi-stakeholder, multi-criterion orientation that is consistent with STS commitments.

Another relevant example is Alla's 2024 dissertation, which proposes the Healthcare Socio-Technical Assessment of Service Robots (H.STAR) framework (Alla 2024). H.STAR is explicitly oriented to healthcare service-robot implementation and brings together Technology Readiness Levels, Human Readiness Levels, and organisational readiness within a single readiness-oriented sociotechnical framework. This work moves beyond narrowly technical assessments and offers a robotics-specific way of conceptualising adoption in healthcare. At the same time, its primary emphasis is on assessing readiness for the broader integration of healthcare service robots, rather than on analysing the situated, relational, and workflow-level dynamics.

The relative scarcity of robotics-specific sociotechnical frameworks constitutes a clear gap in the literature. Robots differ in important ways from many other healthcare technologies that have motivated STS frameworks (such as health information systems). They are embodied, operate in physical environments, interact in real time with patients and staff, and may exercise varying degrees of autonomy. These features intensify questions of workflow integration, safety and infection control, accountability and liability, and the day-to-day coordination of tasks across human and robotic actors. As a result, applying general healthcare STS frameworks is valuable but not always sufficient.

This gap is particularly consequential for the focus of this thesis: *human-robot collaboration* as a subset of healthcare robotics. Accordingly, this thesis uses STS as the primary analytical lens to examine how HRC is configured and sustained in practice, and draws on acceptance models as complementary constructs for characterising stakeholder perceptions that emerge from those configurations. Together, these perspectives inform the analytic questions and empirical approach developed in subsequent chapters.

2.6 Research Aim and Questions

Building on the research objective introduced in Chapter 1 and the synthesis presented in this literature review, this thesis responds to a key gap in the field: the limited number of STS frameworks developed specifically for HRC in healthcare. Accordingly, the aim of this research is to develop a structured sociotechnical framework for understanding and guiding the development and integration of HRC in healthcare settings, with particular attention to the sociotechnical and acceptance-related factors that enable or constrain its sustained use in practice.

In pursuing this aim, the thesis also addresses gaps identified in the scoping review (Section 2.2.2) by (i) expanding empirical attention to underrepresented areas where HRC applications remain rare but potentially valuable, and (ii) addressing the ecological validity gap by conducting empirical research in real-world healthcare settings rather than relying solely on controlled laboratory studies.

To operationalise this aim, the thesis is guided by three research questions:

RQ1: How are HRC technologies developed and introduced into healthcare settings and how do these processes shape their use in healthcare settings?

RQ2: What factors influence the acceptance of HRC technologies in healthcare settings?

RQ3: How can insights into the development, introduction, and acceptance of HRC technologies inform practical guidance for their design and integration in healthcare?

Chapter 3

Research Methodology

This chapter builds on the preceding literature review by translating its conceptual insights and identified gaps into an explicit plan for how the research was designed and conducted. It outlines the methodological foundations of the thesis, beginning with the pragmatic paradigm that supports problem-driven inquiry in complex healthcare contexts. It then presents Design Science Research as the overarching design approach and explains how the Design Science Research Methodology structures the iterative development, demonstration, and evaluation of the thesis artefact. Finally, the chapter summarises the mixed methods used across the empirical studies — exploratory interviews, a quantitative acceptance factors study, and two case studies — and explains how these sources of evidence are synthesised to produce a sociotechnical framework to guide the development and integration of HRC systems in healthcare.

3.1 Research Paradigm: Pragmatism

Paradigms function as conceptual frameworks that shape how knowledge is understood and produced (Leavy 2022). A research paradigm encompasses shared assumptions within a scholarly community concerning ontology (the nature of reality), epistemology (how knowledge is generated), and methodology (appropriate ways of studying phenomena) (Johannesson and Perjons 2021). These assumptions influence how researchers interpret their field and inform their methodological choices (Creswell and Creswell 2017). In line with these considerations, I adopt the pragmatic paradigm to reflect my emphasis on addressing situated and context-dependent research problems through flexible and outcome-oriented inquiry.

Pragmatism emerged in the late nineteenth century through the work of scholars such as Charles Sanders Peirce, William James, John Dewey, and George Herbert Mead (Cherryholmes 1992; Maxcy 2003). Rather than committing to a single philosophical position, pragmatism prioritises the practical value of knowledge and focuses on addressing real-world problems. From this perspective, truth is not absolute but is assessed in terms of its usefulness and consequences within specific contexts (Hevner 2007; Morgan 2014).

Ontologically, pragmatism conceptualises reality as dynamic and shaped through human action and experience. It rejects the notion of a single, fixed reality that can be fully apprehended through objective measurement alone; instead, it recognises the existence of multiple, context-dependent realities (Morgan 2014).

Epistemologically, pragmatism views knowledge as arising from experience, inquiry, and reflection. Knowledge is understood as a tool for engaging with and responding to the world rather than as a direct representation of reality. Beliefs are considered valid insofar as they support effective action and problem resolution, and knowledge is both individually constructed and socially shared (Morgan 2007).

Methodologically, pragmatism emphasises flexibility and the selection of methods based on their suitability for addressing the research question. It does not privilege qualitative or quantitative approaches but supports the use of mixed methods and abductive reasoning, allowing movement between inductive and deductive logic as required (Tashakkori 2010; Morgan 2007). The primary concern is generating findings that are meaningful, actionable, and relevant to practice (Morgan 2014).

Pragmatism is particularly well suited to research related to healthcare, where studies are often conducted in complex, real-world environments characterised by ethical constraints, limited access to participants, safety considerations, and diverse stakeholder needs (Patton 1990). By prioritising the research problem and intended outcomes, a pragmatic approach allows methods to be adapted to contextual constraints while maintaining methodological rigour (Braithwaite et al. 2017). This orientation also supports the integration of different types of data, enabling a more comprehensive understanding of complex healthcare phenomena and enhancing the practical relevance of research findings (Bryman 2006; Tashakkori and Teddlie 2021).

3.2 Research Design: Design Science Research

This thesis adopts *Design Science Research* as its overarching research design. DSR is well suited to research that aims to produce an *artefact* — such as a framework, method, model, or system — that addresses a relevant real-world problem while also generating contributions to knowledge (Hevner et al. 2004; Hevner 2007; Johannesson and Perjons 2021). In contrast to approaches that primarily describe or explain existing phenomena, DSR is explicitly oriented toward purposeful creation and evaluation, where knowledge is advanced through building and studying artefacts in context.

DSR aligns with the pragmatic paradigm underpinning this thesis because it supports inquiry that is both problem-driven and outcome-oriented, and because it enables the integration of multiple methods to generate *actionable insights* for practice.

3.2.1 DSR Framing: The Design Science Research Methodology (DSRM)

This thesis follows the Design Science Research Methodology (DSRM) proposed by Peffers et al. (2007). DSRM operationalises DSR by specifying six core activities that guide how artefacts are motivated, designed, demonstrated, evaluated, and communicated. These activities provide a coherent methodological backbone for structuring the research process and for ensuring *rigour and relevance* across iterative cycles of design.

Figure 3.1 illustrates the DSRM process. While the methodology is often presented as a nominal sequence of six activities, it is inherently iterative. Insights gained during demonstration and evaluation frequently inform revisions to earlier stages, particularly the definition of objectives and the design of the artefact.

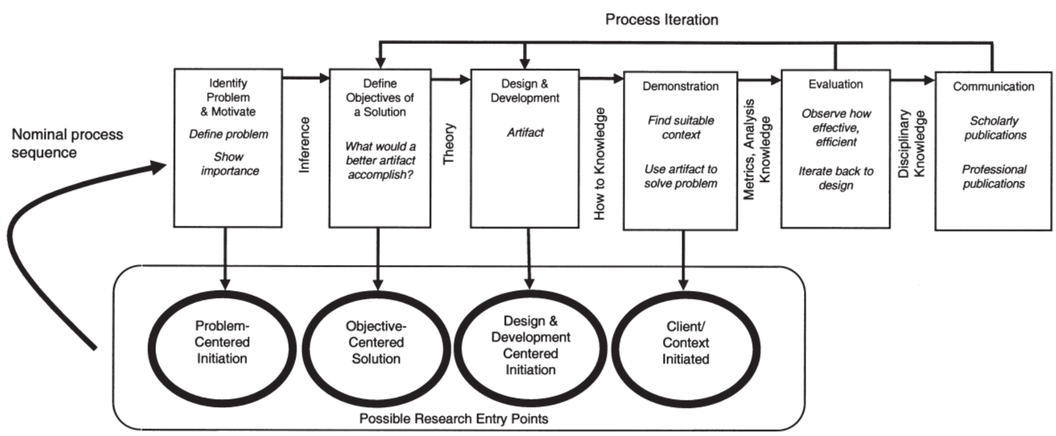

Figure 3.1: Design Science Research Methodology (DSRM) showing the nominal process sequence, iterative feedback loops, and possible research entry points (adapted from (Peffers et al. 2007)).

The six DSRM activities enacted in this thesis are:

1. **Problem identification and motivation**, where the research problem is defined and its relevance is established;
2. **Definition of objectives for a solution**, which articulates what an artefact should accomplish;
3. **Design and development**, involving the construction of the artefact;
4. **Demonstration**, where the artefact is applied within an appropriate context to address the identified problem;
5. **Evaluation**, assessing the artefact's effectiveness and utility using suitable criteria and methods; and
6. **Communication**, in which the artefact and associated knowledge contributions are disseminated to scholarly and professional audiences.

Consistent with the iterative logic depicted in Figure 3.1, the DSRM activities in this thesis are not treated as strictly linear. Findings from exploratory, design, and evaluative phases inform successive refinements of the framework and the formulation of design principles. This learning-through-building approach reflects the core epistemological stance of DSR, where knowledge emerges through iterative design, use, and reflection (Hevner et al. 2004; Johannesson and Perjons 2021).

3.2.2 Description of the Artefact

The primary DSR artefact produced by this thesis is a **framework** that developers and integrators can use to make design decisions about HRC systems in healthcare. The framework is intended to:

- represent the key sociotechnical factors shaping the *development and integration* of HRC technologies in *healthcare settings*;
- provide a structured way to anticipate and navigate challenges related to acceptance, workflow alignment, organisational fit, and sustained use;
- translate empirical insights into *actionable insights* and design principles for HRC design and integration practice.

3.2.3 Mapping the Thesis to the DSRM Activities

The DSRM activities are implemented in this thesis through a sequence of studies: literature review, exploratory interviews, a quantitative acceptance study, framework development, and two case studies used for demonstration and evaluation. Table 3.1 summarises how each activity is operationalised.

Table 3.1: Mapping of Peffers' DSRM activities to thesis components.

DSRM Activity	Thesis Operationalisation
Problem identification and motivation	Literature review establishing the need for sociotechnically grounded guidance for HRC development and integration in healthcare; articulation of RQ1–RQ3 and research objective.
Define objectives for a solution	Exploratory interviews with stakeholders involved in healthcare technology development and integration (e.g., robotics, AI, digital health) to derive what practical guidance should enable; quantitative acceptance study to establish relevant acceptance factors and stakeholder considerations.
Design and development	Synthesis of findings from the literature review, exploratory interviews, and acceptance study to build the initial framework and associated design principles.
Demonstration	Application of the framework to two healthcare HRC cases: (1) design of an HRC system for hospital Rapid Response Systems; (2) analysis of Lokomat use in a rehabilitation setting.
Evaluation	Case study-based evaluation using semi-structured interviews and observations to assess framework usefulness, completeness, clarity, and practical fit.
Communication	Thesis chapters reporting artefact rationale, development process, case applications, evaluation findings, and resulting actionable guidance for developers and integrators.

3.3 Methods

Consistent with pragmatism and DSR, the thesis uses mixed methods selected for their fitness to purpose, enabling both exploratory insight (RQ1–RQ2) and prescriptive output (RQ3). The empirical components are summarised below; detailed procedures are presented in the relevant chapters.

3.3.1 Exploratory Interviews

To support RQ1 and inform the early design of the thesis artefact, exploratory semi-structured interviews were conducted with stakeholders involved in the development, procurement, training, or integration of healthcare technologies. The interviews were used to surface practical barriers and facilitators experienced in real-world projects, with particular attention to integration constraints (e.g., workflow fit, organisational aspects, and governance) and how such challenges were addressed in practice. In

DSR terms, these interviews contributed to clarifying what the framework should enable by translating lived project experience into actionable needs and considerations that the artefact must account for.

Sampling and participants. Fifteen participants were recruited using purposive sampling to obtain a diverse range of perspectives across healthcare technology projects. Recruitment was conducted through professional networks, including LinkedIn, direct email outreach, and relevant social media postings. Participants included developers, researchers, consultants, and clinicians with experience in technology development, implementation, training, or procurement within healthcare contexts. Given the limited pool of professionals with direct HRC implementation experience in healthcare, participation was not restricted to HRC-only projects. Instead, I included stakeholders involved in adjacent technologies (e.g., AI decision support and digital health systems) where integration work similarly involves workflow alignment, governance, safety assurance, training, and stakeholder negotiation. This broader sampling strategy supported analytic transferability by capturing recurring sociotechnical integration patterns likely to also shape HRC projects, while still foregrounding robotics-relevant considerations where participants had them.

Data collection. Interviews were conducted online via Zoom or Microsoft Teams, with data collection spanning March 2023 to February 2025. Participants received an information sheet and consent form prior to scheduling. Interviews were designed to take approximately one hour; in practice they ranged from 45 minutes to 1.5 hours depending on participant availability and depth of discussion. A semi-structured interview guide was used to explore participants' technology project experiences, perceived integration challenges and enablers, and lessons learned regarding what supports successful development, integration, and sustained use. All interviews were audio-recorded with participant consent.

Transcription and analysis. Recordings were transcribed using OpenAI's Whisper model and then manually reviewed to correct errors and produce a verbatim transcript. Transcripts were subsequently shared with participants for review and confirmation. Qualitative analysis followed reflexive thematic analysis using Braun and Clarke's six-phase approach (Braun and Clarke 2012). Analysis began with familiarisation through repeated reading, followed by iterative coding and theme development to identify recurring patterns, tensions, and practical needs relevant to healthcare technology integration. NVivo 15 supported data management and coding, while Microsoft Excel and Miro were used to assist with organising codes, mapping relationships between themes, and synthesising insights into considerations that informed the framework.

Reasoning approach. Analysis followed an abductive logic consistent with pragmatism. Initial coding was primarily data-driven to capture participants' accounts in their own terms, while being informed by sensitising concepts from the literature review and the research questions. Theme development then proceeded iteratively by moving between emerging patterns in the data and relevant sociotechnical and technology-integration concepts to refine interpretations and translate themes into actionable implications for the framework. This iterative cycling supported both discovery of unanticipated issues and the development of prescriptive guidance grounded in empirical evidence.

3.3.2 Acceptance Factors Study

To address RQ2, a quantitative acceptance study was conducted in a hospital context. The purpose of this study was exploratory and design-oriented: rather than producing statistically generalisable estimates across all healthcare contexts, it was used to examine acceptance determinants within a concrete and plausible HRC application, and to identify factors that may be particularly salient for HRC. This context-specific focus was consistent with the pragmatic stance of the thesis and the DSR objective of producing actionable guidance. Given the diversity of healthcare settings and HRC applications, constraining the study to a specific implementation scenario provided a feasible way to elicit empirically grounded acceptance considerations that could inform the framework and its design principles.

Context and study scenario. The study focused on a proposed HRC system intended to support hospital Rapid Response Systems (RRS). Participants were provided with a brief overview of RRS and plain-language definitions of AI and robotics to establish a shared baseline of understanding. The survey then introduced the proposed robot and its intended role within the hospital scenario, after which participants completed measures related to acceptance and associated constructs. Full details of the scenario and research model are reported in Chapter 5.

Sampling and recruitment. Data collection was conducted at University of Canberra Hospital (UCH) from 12 February 2024 to 12 March 2024. UCH is the largest purpose-built rehabilitation centre in the region, equipped with a rapid re-

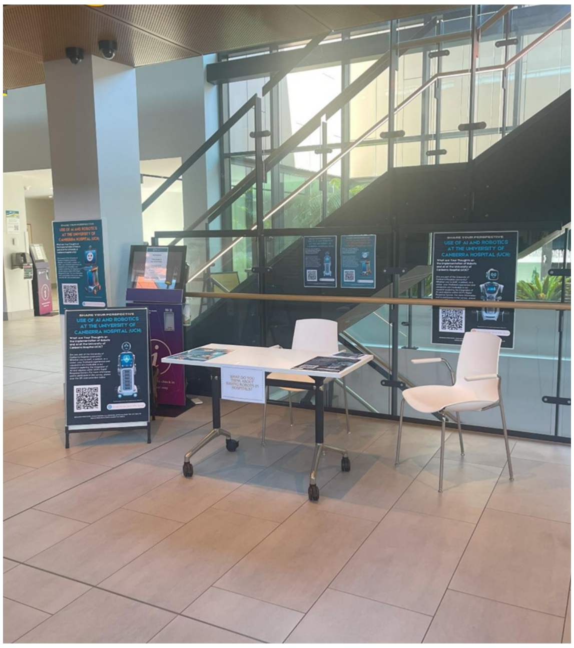

Figure 3.2: Recruitment station set up in the hospital foyer at University of Canberra Hospital to invite staff, patients, and visitors to participate in the survey.

sponse system and designed to support research activities. To capture perspectives across key stakeholder groups, stratified convenience sampling was used across stakeholder groups relevant to hospital technology adoption, including staff, patients, and visitors. Eligibility criteria were that participants be at least 18 years of age, proficient in English, and cognitively capable of providing informed consent and completing the survey.

The questionnaire was hosted on Qualtrics and could be accessed via QR code on participants' personal devices or through a direct link; hospital devices were also made available to support participation. Recruitment was supported through a staffed booth in a high-traffic hospital area, posters placed throughout the hospital, and internal email distribution to staff. Hospital staff also assisted in identifying potential participants and, where needed, supporting survey completion.

Figure 3.2 shows the recruitment station set up in the hospital foyer to invite patients, visitors, and staff to participate in the study. Hospital staff also assisted in identifying potential participants and, where needed, supporting survey completion.

In total, 99 responses were recorded; 74 were retained for analysis after removing incomplete entries.

Measures. Acceptance was modelled using an adapted UTAUT instrument, extended with three constructs hypothesised to be especially relevant to HRC in healthcare: trust, ethical concerns, and perceived risk. The questionnaire included demographic and background questions, followed by measurement items for each construct. Full item wording and scale details are provided in Chapter C and described in Chapter 5.

Analysis. Data were analysed using partial least squares structural equation modelling (PLS-SEM) to support the exploratory nature of the study and the evaluation of a structural model with multiple constructs in a relatively small sample. Analyses were conducted in SmartPLS 4 (Ringle et al. 2024). The full analysis procedure and results are presented in Chapter 5.

Minimum sample size calculations. The minimum sample size was calculated according to the PLS-SEM guidelines provided by Hair et al. (2022). To detect path coefficients between 0.21 and 0.30 with 80% power at a 5% significance level, a sample of 69 was required. Since the retained sample included 74 participants, it surpassed this minimum threshold. Due to the limited body of existing research on HRC in RRS, this study was framed as exploratory. While the sample size restricts broad generalisability, it was adequate for detecting preliminary patterns and relationships. Thus, the findings offer an initial empirical basis for understanding acceptance of HRC in RRS and for guiding future research using larger and more diverse samples.

3.3.3 Case Studies

Two case studies were used to demonstrate and evaluate the framework in distinct healthcare settings:

- **Case 1:** Design of an HRC system for Rapid Response Systems.
- **Case 2:** Analysing the use of Lokomat in a rehabilitation setting.

It should be clarified that the term *evaluate* is used here in the Design Science Research sense. In this thesis, evaluation refers to the case-based application and reflective assessment of STEER-H in relation to its intended purpose: to structure analysis, make sociotechnical considerations visible, and identify areas where the framework required clarification, refinement, or contextual tailoring. The case studies therefore served as a means of examining the framework's explanatory and practical value in relation to real-world healthcare HRC contexts. This should be distinguished from a formal evaluation study of STEER-H as an applied tool. For this reason, a qualitative case study design was appropriate, as it allowed the framework to be examined in relation to the contextual conditions, stakeholder perspectives, and situated work practices that shape healthcare HRC integration.

A qualitative case study design was adopted to generate in-depth, context-sensitive understanding of how sociotechnical factors shape HRC development and integration in practice. Case studies are appropriate when the research aims to examine a contemporary phenomenon within its real-world setting and when contextual conditions are central to interpretation (Yin 2025). This is particularly relevant for healthcare HRC and the application of the proposed framework in which the organisational routines, spatial layouts, professional roles, and patient-care priorities strongly influence how technology is used, adopted, and sustained.

Both cases were conducted at UCH, similar to the Section 3.3.2. Data collection for both cases involved an intensive one-week onsite period, during which I was embedded in the hospital environment to conduct observations and semi-structured interviews. This approach enabled direct engagement with local routines and constraints and supported triangulation between what participants reported and what was observed in situ.

Sampling and participants. Sampling was purposive and criterion-based, targeting participants with direct involvement in, or experience of, the focal work practices in each setting. For both case studies, recruitment was facilitated through local contacts at UCH and clinical managers, and aimed to capture a range of perspectives relevant to HRC integration (e.g., clinical staff involved in day-to-day care delivery, operational or managerial stakeholders with responsibility for workflow and governance, and technical or support roles where applicable). Participants were eligible if they were aged ≥ 18 years and able to provide informed consent.

- **Case 1 (HRC for Rapid Response System).** This case study involved 11 participants, including 8 nursing staff and 3 medical staff. Nursing participants included Clinical Development Nurses, Clinical Nurse Educators, Clinical Nursing Consultants, and Registered Nurses, while medical participants held senior medical and clinical leadership roles.
- **Case 2 (Lokomat Rehabilitation).** This case study involved 8 participants. Most were physiotherapists and physiotherapy assistants who had been trained to use the Lokomat and were actively using it in rehabilitation practice. In addition, 2 participants were involved in management, procurement, and the introduction of the Lokomat to UCH.

Data collection. Multiple qualitative data sources were collected to support triangulation. Semi-structured interviews were used to capture stakeholder perceptions, roles, and integration challenges, while non-participant observations were used to document workflows, spatial arrangements, and interactions between clinicians, patients, and technology. In addition, relevant publicly accessible hospital documents were used to corroborate and enrich the interview and observation data.

Transcription and analysis. All interviews were audio-recorded with participant consent and transcribed verbatim. Observation notes and documentary materials were consolidated into a single qualitative dataset for each case. Analysis followed a thematic approach, combining inductive coding with a deductive layer informed by the sociotechnical framework layers and constructs. Initial codes were generated within each case, then iteratively grouped into higher-order themes.

3.4 Framework Development and Evaluation

Framework development proceeded through the synthesis of: (i) the literature review, (ii) exploratory interview themes, and (iii) acceptance study findings. This synthesis informed the definition of framework layers, dimensions, relationships, and the form of guidance provided (see Chapter 6 for details).

Consistent with DSRM, evaluation was conducted after initial framework development through demonstration and reflective assessment in real-world contexts. The framework was applied within two case studies to examine how it performs as a practical decision-support resource for developers and integrators, and to identify where it required clarification, extension, or contextual tailoring. Qualitative evidence was drawn from case interviews and observations and triangulated through cross-case comparison to support a robust assessment of framework value and limitations.

3.5 Rigour and Relevance Considerations

DSR requires attention to both *rigour* (grounding in existing knowledge) and *relevance* (connection to real-world problems) (Hevner et al. 2004; Hevner 2007). In this thesis, rigour is supported through:

- theoretical and empirical grounding from the literature review and sociotechnical systems scholarship;

- systematic qualitative analysis (thematic analysis) across exploratory and evaluative components;
- quantitative modelling using PLS-SEM to support acceptance-related insights.

Relevance is supported through engagement with stakeholders involved in real healthcare technology development and integration, and through evaluation in real-world healthcare cases. This combination enables the framework to remain sensitive to the practical constraints and complexities of healthcare settings while remaining analytically defensible.

3.6 Ethics

All research activities involving human participants were conducted in accordance with the National Statement on Ethical Conduct in Human Research and the relevant institutional requirements. Ethical approval was obtained prior to data collection for each empirical component of the thesis.

Approval for the exploratory interview study was granted by the Australian National University (ANU) Human Research Ethics Committee (HREC) (Protocol 2021/832). The quantitative acceptance study conducted at the University of Canberra Hospital received approval from the ACT Health HREC (Protocol 2023.LRE.00217), with subsequent ANU HREC approval (H/2024/0499). The two case studies used for framework demonstration and evaluation were approved by the ACT Health HREC (Protocol 2024.LRE.00085), with subsequent ANU HREC approval (H/2024/0969).

Across all studies, participants were provided with written information sheets detailing the study purpose, procedures, risks, and benefits, and they gave informed consent prior to participation. Participation was voluntary, and participants could withdraw at any time without consequence. Data were collected, stored, and analysed in accordance with approved data management plans, with all identifying information removed or anonymised to protect participant confidentiality.

All five ethics approval letters (three from the ANU HREC and two from the ACT Health HREC), together with the three corresponding protocol documents, are available upon reasonable request.

3.7 Conclusion

In this chapter, I set out the methodological approach used to address the research aim of this thesis. It established pragmatism as the guiding research paradigm and Design Science Research as the overarching design logic, with the Design Science Research Methodology providing a structured yet iterative process for developing, demonstrating, and evaluating the thesis artefact. In doing so, the chapter positioned the study as both analytically grounded and oriented toward practical contribution in complex healthcare settings.

The chapter further summarised the mixed methods used across the empirical studies: exploratory interviews, a quantitative acceptance factors study, and two qualitative case studies. Each method contributes a distinct form of evidence, and together they support the synthesis of findings into a sociotechnical framework for guiding the development and integration of HRC systems in healthcare.

Finally, the chapter outlined the steps taken to ensure rigour, relevance, and ethical conduct across the research. The next chapter presents the findings from the exploratory interviews, focusing on how stakeholders involved in healthcare technology development and integration described the practical challenges, enabling factors, and sociotechnical considerations that shape these processes in practice.

Chapter 4

Exploratory Expert Insights

This chapter presents findings from the exploratory semi-structured interviews conducted to address **RQ1** and to inform the early development of the framework. The interviews elicited practitioner and expert perspectives on the practical barriers, enablers, and decision points involved in developing and integrating complex technologies in healthcare, with particular attention to issues relevant to HRC. Using reflexive thematic analysis, the chapter synthesises recurring patterns across participants' accounts into a set of themes that highlight key sociotechnical considerations shaping this process.

4.1 Participant details

To contextualise the insights presented in this chapter, this section summarises participants' professional roles, backgrounds, and areas of expertise. Table 4.1 provides an overview of participants' roles, key expertise, the technologies discussed during interviews, and their primary domains of work.

4.2 Findings

The themes reported in this section capture how participants from varied professional backgrounds understand the conditions that shape the development and integration of healthcare technologies, including issues salient to HRC. The findings are grounded in participants' concrete experiences of designing, procuring, deploying, and using technologies across diverse healthcare settings, alongside reflective insights drawn from their roles within the broader healthcare innovation ecosystem. Illustrative quotations are included to preserve the specificity of these accounts. It should be noted that the themes are not mutually exclusive; rather, they describe interdependent dynamics that participants repeatedly encountered. The codebook is included in Chapter B, organised by code category, code, and description.

ID	Role	Key Expertise	Technologies Discussed	Domain
EP01	Healthcare professional, intensive care	Clinical innovation; ICU use of advanced technologies	AI-based monitoring systems, life-support equipment, robotic systems	Clinical
EP02	Healthcare professional, management	Rehabilitation; procurement and integration of rehabilitation robotics	Rehabilitation robotics	Clinical, Management
EP03	Engineer, Medtech Consultant	Regulatory strategy; early device development; AI applications	AI systems, medical devices	Development, Regulation
EP04	Robotics Researcher, Software Developer	Human–robot interaction; design research	Social robots in hospitals	Research, Development
EP05	Medical Physicist, AI Startup Founder	AI in radiation therapy; regulatory pathways; open-source medical technologies	AI-enabled radiation therapy tools, open-source platforms	Clinical, Development
EP06	Machine Learning Researcher	EMR-based AI models; model explainability; clinical integration	Clinical decision support AI models	Research, Development
EP07	Healthcare Systems Researcher, Consultant	Change management; systemic barriers; stakeholder perceptions	AI decision support tools	Research, Consulting
EP08	Innovation Strategist, Health Tech Investor	Consumer health technology; AI evaluation; market adoption	Consumer health platforms, AI for chronic care	Business
EP09	Medical Scientist, Medtech Entrepreneur	Clinical validation; patient engagement; stakeholder alignment	AI diagnostics, EMR integration	Clinical, Entrepreneurship
EP10	Former GP, Health Tech Founder	AI and automation for chronic care management	Generative AI, chronic care automation platforms	Clinical, Entrepreneurship
EP11	Orthopaedic Surgical Fellow	Robotic surgery adoption; digital workflows; clinical integration	Robotic-assisted surgery, digital documentation	Clinical
EP12	Rehabilitation Robotics Startup Founder	Rehabilitation robotics; hospital trials; patient outcomes	Rehabilitation robots	Clinical, Entrepreneurship
EP13	Medical robotics researcher and developer	User-centred design; translational innovation in medical robotics	Medical robotic systems for nursing assistance	Research, Development
EP14	Robotics Engineer, Innovation Centre	Collaborative robotics deployment	Collaborative robots, exoskeletons	Development
EP15	AI and Robotics Researcher for Aged Care	Assistive robotics design; co-design approaches; HCI in aged care	Assistive and social robots for aged care	Research, Development

Table 4.1: Overview of study participants, roles, expertise, and domains

4.2.1 Theme 1: An Interwoven Stakeholder Ecosystem

Participants described the healthcare technology ecosystem as a dense and interdependent mesh of actors, each with distinct roles, constraints, and responsibilities. Engineers rely on clinicians to articulate clinical needs; clinicians, in turn, depend on administrators to allocate resources; administrators look to regulators and insurers to secure compliance and funding. At the centre of this network are patients, whose outcomes ultimately hinge on how well these various actors align their efforts.

Several participants reflected on the difficulty of achieving that alignment. One noted:

> "At the end of the day, healthcare is very complicated, and there's a whole range of different stakeholders and for any change to the healthcare system, you need to be able to make the relevant arguments or the relevant communications to them to be able to convince them that this is something worth implementing." (EP09)

Participants repeatedly emphasised the practical implications for development teams:

> "You probably need to make sure that not just the people on the ground like your product, but also the administrators who are actually going to be paying the bills. You need, as a software engineer who understands what's possible, to be talking to the people who know what's needed and who will be buying your product." (EP05)

The same participant later added that key stakeholders often only become visible once implementation begins:

> "So many stakeholders only come out of the woodwork when something is actually deployed in the hospital system" (EP05)

Another participant recounted how a seemingly straightforward aged-care project soon revealed a broader constellation of actors:

> "managers, union rep, the facility's risk manager, IT services . . . and each of them has completely different thoughts and needs and concerns. . . " (EP15)

Together, these accounts frame stakeholder alignment as an ongoing negotiation rather than a one-off "buy-in" task—one that often expands during deployment as hidden governance, risk, and operational actors become salient.

This complexity sets the stage for the sub-themes that follow, which examine how participants navigated collaboration across silos, the role of early stakeholder engagement, and the tensions that emerge when different priorities and values collide within shared decision spaces.

Sub-theme 1-1: Bridging Silos through Collaboration

Participants described collaboration not as an optional feature of health technology development, but as a structural necessity. Bringing new technologies into healthcare requires the coordination of diverse forms of expertise, including clinical, technical, managerial, and regulatory. No single discipline can carry a project from conception to adoption. As one participant put it:

> “Typically, the process involves progressing along four different axes... clinical performance, business performance, technical performance, and regulatory performance... you need clinical expertise, you need business expertise, you need political expertise, you need everything.” (EP03)

For many, the value of collaboration was grounded in direct experience. As participants explained:

> “It’s not an idea that comes from the software engineer’s head... it actually needs to be the software engineer in tight communication with the healthcare industry and its whole chain” (EP05)

Another participant also mentioned:

> “Speaking with clinicians from day one is super important to validate the unmet medical need.” (EP09)

Others echoed this, pointing out that meaningful innovation involves voices from ethics, policy, data infrastructure, and management — not just technical domains (EP06, EP14). The importance of iterative feedback was also highlighted.

Importantly, collaboration is not a one-way process for developers. Clinicians and managers also rely on technical experts to provide better care to patients. A physiotherapist involved in robotic rehabilitation explained,

> “Even when we get these robots... what we don’t know is how long do you need to put a patient on that device for them to get an improvement” (EP02)

In such cases, developers are not just responding to needs — they are helping to define the knowledge base alongside clinicians. Yet this kind of collaboration is not always easy. Many pointed to disciplinary silos and lack of clear communication channels as persistent barriers, as one participant mentioned:

> "There needs to be a lot more collaborations... developers, clinicians and managers... right now there's a disconnect between everyone's understanding and communication" (EP06).

Another participant explained:

> "It's very easy to be stuck in your own discipline... progress needs to come by better communication between those disciplines." (EP03)

Participants with clinical backgrounds also pointed out that these silos exist even within clinical teams. A participant described the challenge of integrating multiple health disciplines, each with different roles, training, and professional cultures (EP02). Another participant reflected on the complex dynamics within multidisciplinary care teams, where different value systems and professional hierarchies must somehow converge around patient care (EP07).

In some cases, deeply ingrained professional identities can hinder open collaboration. One clinician-turned-founder observed:

> "People assume too much, unfortunately... I think maybe it's because in healthcare you spend nine years training to become a doctor and become an expert. Now, all of a sudden, you want me to take on the persona of like a beginner and a non-expert and listen to you. No, I know better than you. You don't know what I know. I've studied, I've trained, I am the expert. So I think that's the issue and I don't see enough of the humility that's required. There needs to be a beginner mindset." (EP10)

Despite these barriers, participants identified strategies to enable smoother collaboration. The concept of "champions" emerged as an effective model: trusted staff who receive advanced training and become in-house advocates and trainers for new tools.

> "We train staff members and give them more training than what is required, but then we give them the job of training all the others." (EP02)

Sub-theme 1-2: Early and Inclusive Stakeholder Engagement

Participants emphasised that engaging stakeholders early in the design and development process is not only beneficial but essential. While collaboration involves sustained, day-to-day interaction among developers and clinical teams, stakeholder engagement was framed as a broader and more strategic practice, aimed at ensuring that the needs, constraints, and concerns of all relevant actors are recognised from the outset. When engagement happens too late or is entirely absent, technologies often fail to align with the realities of clinical practice and frontline needs.

This absence of consultation can result in products that disrupt workflows or miss the mark entirely. One healthcare professional expressed frustration at being excluded from the early phases of technology development:

> "We are not consulted in the design phase... each [device manufacturer] seems to be working in a silo... all these machines are dumped into a space without any feedback from us as frontline health providers." (EP01)

Another participant pointed out that patients, who should be at the centre, are often overlooked due to structural issues such as funding and reimbursement incentives:

> "Patients... nobody is thinking about the patient. Zero. And I think it's because the incentive... the payer models focus on activity and the people doing the activity are the doctors." (EP10)

Others described early engagement as a critical step for ensuring relevance, alignment, and efficiency throughout the innovation process. A participant involved in clinical innovation and entrepreneurship explained:

> "Engaging with all of the stakeholders... on day one makes sure that you don't get any surprises as you move further down the pipeline." (EP09)

Several participants spoke about the need to begin with a blank slate, starting from user needs rather than preformed solutions. A participant articulated this approach clearly:

> "If you really want to create quality, you need to start with a white page... What problem do we want to solve? Who is the user and what is their problem?" (EP03)

Beyond informing design decisions, early engagement was also described as essential for building trust among those whose support is critical to implementation. One robotics researcher gave a detailed example of how their team prioritised early conversations with hospital stakeholders — not only to understand user needs but also to establish a foundation of mutual trust:

> "We met with different user groups in the hospital, mainly patients and guests, and sat down, did an interview of their needs... We first interviewed staff. We had a staff kickoff to build trust with staff and also understand their challenges." (EP04)

By involving staff from the beginning and responding to their concerns, the research team was able to foster a sense of partnership rather than imposition. Other participants echoed this view, noting that early, inclusive engagement helps build credibility and strengthens the long-term viability of a project (EP08). Involving a broad range of voices early — including clinicians, patients, caregivers, and even family members — was seen not only as a strategy for good design, but as a responsible and relational practice. As one researcher working in aged care put it:

> "We bring in family, nurses, and the residents themselves... I think this is a responsible way going forward... important for building some level of trust." (EP15)

Across these reflections, early engagement emerged not just as a planning tool, but as a signal of respect — one that sets the tone for successful adoption later on.

Sub-theme 1-3: Navigating Competing Values and Priorities

Participants highlighted that one of the central challenges in implementing new healthcare technologies lies in reconciling the differing priorities of various stakeholders. While all may be aligned in principle around improving patient care, they often evaluate technologies through very different lenses: financial, clinical, operational, or strategic. One participant illustrated this complexity with a breakdown of how the same technology might be judged by different roles:

> "The administrator likes the fact that it halves the time that it takes a radiotherapist to do the job... tick, you've passed their budget. The person on the ground is, does this achieve everything I want it to achieve without it being a mighty pain? And then someone who's doing the validation work, is this actually having better patient outcomes?" (EP05)

This participant went on to explain, if any one of these boxes is not ticked — especially if it increases complexity for staff or adds cost without clear savings — implementation may quietly stall:

> "If you come in with the most whiz-bang thing ever, but someone has to absolutely upend the whole workflow... then they'll never do it." (EP05)

This tension becomes even more pronounced when commercial priorities enter the equation. Technologies must often navigate between medical expectations and investor demands, which are not always aligned:

> "You have this tension between the commercial side of things and the medical and scientific side... you have to make sure that you marry

> [them] well together." (EP09)

This tension also surfaced in the design of clinical trials, where teams must balance scientific rigour with the requirements of regulators, investors, and funding bodies. As one participant explained:

> "Understanding how to best design clinical trials to make sure they reach the appropriate endpoints... investors, government bodies are going to want to see that burden of evidence." (EP09)

A similar divide was described by another participant working on robotics in rehabilitation:

> "It's always the same... engineers thinking in perfect lab settings, clinicians thinking in busy wards, managers and admins thinking in budgets." (EP12)

4.2.2 Theme 2: Context-Aware Design and Development

Several participants stressed that, for technologies to be truly effective in healthcare, they must be developed with a deep awareness of the specific clinical environments in which they will be used. This requires moving beyond abstract user requirements or simulated testing environments, and instead engaging directly with the people, practices, and pressures of real-world healthcare settings.

As one participant emphasised, understanding the day-to-day realities of healthcare delivery is essential:

> "You should probably spend some time in a hospital. Following nurses around if it's a thing for nurses or following doctors around... Because you need... to be talking to the people who know what's needed and who will be buying your product." (EP05)

Another participant described how they worked closely with hospital staff, beginning with a site visit to understand physical constraints and practical challenges (EP04).

In this view, context-aware development is not just about observing workflows but about forming ongoing partnerships. Several participants highlighted the importance of working closely with clinical partners who are willing to trial and help adapt technologies in situ:

> "You need a partner. So, you probably need a hospital partner or someone who is willing to test out your software... you really need to be deploying something into a clinical scenario." (EP05)

Others drew vivid analogies to underscore the importance of immersion and empathy in product development. One health tech founder framed it this way:

> "If you want to understand a culture, the best way to do it is to learn the language and to be on the ground and to eat their food... let's start with the product manager – do product managers eat the food of the customers that they're serving? Do product managers talk the same language as the customers that they're serving? Do developers who are building this talk the same language? Do they eat the food?" (EP10)

This emphasis on language, culture, and direct experience resonated with a broader concern voiced by several participants — that much current development happens in conditions that are too far removed from the complexity of clinical care. One researcher put it succinctly:

> "I think there is a huge gap between what we test in simulation and labs and what nurses actually do when they're under pressure." (EP13)

The interviews highlighted four main areas of contextual information that seemed important to them: workflows and tasks, existing tools and technologies, the physical environment, and organisational factors. The following sub-themes focus on each of these areas.

Sub-theme 2-1: Interoperability and Integration with Existing Tools and Systems

Participants emphasised that health technologies must be designed with deep awareness of the systems and tools already in place within clinical environments. The effectiveness of a new device or platform depends not only on its standalone functionality, but on its ability to integrate — both technically and operationally — with existing infrastructures, workflows, and digital health systems. Several interviewees described the sheer density of technologies already present in care settings as both a technical and psychological barrier. One ICU clinician painted a vivid picture of device overpopulation:

> "If you now go to see a patient, it's very hard to find the patient. You will only see these machines first... dialysis machines, ventilators, infusion pumps... there's more machines than humans around any intensive care patient at this time." (EP01)

This level of saturation creates constraints on space, power, and staff attention — and highlights the need for any new technology to work harmoniously with the existing ecosystem. The challenge of integration was a consistent theme across both clinical and technical roles. For instance, one founder described how hospital firewalls interfered with secure data transfer from their software:

> "They were injecting a certificate... my software was trying to be very secure... and [the hospital system] was breaking the encryption handshake." (EP05)

Solving this required aligning cybersecurity protocols between developer and institution — highlighting the friction that can emerge when systems are not designed with mutual visibility.

Digital Health Records (DHRs) or Electronic Medical Records (EMRs) were identified as particularly critical points of integration. One entrepreneur reflected:

> "If you're... developing a product that cannot be readily implemented or integrated into EMR... you're going to find yourself essentially rewriting the whole thing." (EP09)

Another participant echoed that poorly integrated tools, no matter how well-intentioned, would likely be rejected if not integrated properly (EP05).

Participants with experience in aged care or rehabilitation settings stressed the need for simplicity and strategic restraint. One founder deliberately designed their robot to avoid interacting with core clinical systems, saying:

> "It doesn't integrate with nurse call or meds dispensing or anything... it's pretty standalone, which I think staff liked...less to configure or cross-check." (EP15)

Similarly, another participant cautioned against overloading technologies with features no one asked for:

> "Do they want that? You know, sometimes less is more." (EP14)

Sub-theme 2-2: Spatial Constraints and Environmental Fit

Participants highlighted the critical, and often underestimated, influence of physical environments on the successful adoption and operation of healthcare technologies. Many pointed out that technologies are frequently designed in lab settings or with abstract user requirements in mind — without fully accounting for the spatial constraints of clinical care, from ICU bays to rehabilitation gyms to aged care corridors.

One participant, reflecting on intensive care unit design, described how the physical footprint of technology has already reshaped the clinical environment:

> "The whole intensive care design has been redesigned to include a million power outlets to power all these gadgets." (EP01)

They described the complexity of these spaces as a:

> "Bird's nest of wires and tubes and blood moving through and electrical cables." (EP01)

They noted that their team had worked on finding a solution to reduce occupational health hazards and improve care efficiency (EP01). Their insight points to the value of holistic spatial planning that integrates technology as part of the care setting, rather than adding it on top.

When it comes to robotic technologies, these considerations take on heightened importance due to their complexity and physical presence. Participants noted that hospitals and aged care facilities are rarely designed with robots in mind. Corridors are narrow, storage space is limited, and patient rooms often have little flexibility for large or mobile equipment. One robotics researcher explained:

> "These hospitals have narrow corridors and if someone's wheeling down a bed with a sick patient on it we don't want to be in the way of that emergency situation." (EP04)

As a result, their team made the decision to constrain the robot's movement:

> "We made it static because we realized that we didn't want to get in the way of emergency situations." (EP04)

Another participant captured the broader challenge succinctly:

> "Wards aren't built for robots... let alone the risks of running into patients." (EP13)

In aged care contexts, these spatial concerns became even more pronounced. A participant working with social robots in residential care described needing to ensure the robot could traverse minor floor changes:

> "We had to make sure the robot could handle those little metal thresholds between carpet and vinyl... for a small wheeled robot that's basically a cliff." (EP15)

They also described the unpredictability of aged care environments:

> “There’s recliner chairs, walkers parked at odd angles, people moving slowly, maybe a visiting toddler on the floor... it only takes one incident or near miss for staff to lose trust completely.” (EP15)

Space was also a logistical consideration in rehabilitation settings. One physiotherapist noted that, during their procurement process, physical space was a primary concern. For a rehabilitation robot to be used consistently, it needed to be located where therapy already happens:

> “If you don’t locate the robot where the rest of the therapy is occurring, [it] might not get used... So the wisest place to put the robot is in the gym. However, then that means it takes up space in the gym.” (EP02)

In such settings, competing demands on space must be carefully managed to avoid unintended trade-offs between technological innovation and practical usability.

Physical space in care settings is typically shared by many stakeholders — including those who may never interact directly with a device or robot. This makes spatial design an important consideration for implementation. As one researcher recalled from an aged care robot trial:

> "A staff member put it plainly: honestly I just need it to not get in my way.” (EP15)

Sub-theme 2-3: Synchronising with Daily Workflows

Across interviews, participants consistently described clinical and care workflows as the central gatekeeper for whether a new technology is adopted, used, or sidelined. No matter how advanced a system is, if it disrupts daily routines or demands too much adaptation, it risks being ignored. As one participant put it bluntly:

> “You could have the most amazing idea ever, but then if it doesn’t integrate well into clinical workflows... you’re going to face a lot of challenges around clinical adoption.” (EP09)

This was especially evident in high-intensity environments such as intensive care units. One ICU clinician recalled how the space had become saturated with tools and equipment, making every new addition a logistical and cognitive burden:

> “There’s more machines than humans around any intensive care patient at this time.” (EP01)

Even newer, more efficient ventilators were rejected because staff were more familiar with existing models—highlighting how familiarity, routine, and established practices can outweigh performance improvements in the early stages of adoption (EP01).

Several participants identified "ease of integration" as a core requirement for success. For some, this meant minimizing training time. A machine learning researcher explained:

> "You don't want to build a system that requires your clinician to sit on a six-month course... clinicians will never get more than 10 minutes of time to do anything." (EP06)

Training wasn't seen as a one-off hurdle but a systemic constraint—every additional complexity multiplies the cost and risk of uptake across large, rotating teams of professionals.

Participants also pointed to more subtle mismatches between how engineers conceptualise success and how care work unfolds. One noted that developers often focus on technical performance, while clinicians focus on fit within existing routines:

> "If the motor torque is right and the control algorithms are stable, then that's the job done... but from my side... if it throws off the therapy schedule or takes too long, then it just doesn't get used." (EP12)

Participants noted that even seemingly small disruptions can accumulate to create major barriers. Software updates, new login systems, or additional devices can fracture the user experience and lead to disengagement. As one participant said:

> "Doctors can't deal with a lot of different devices or a lot of different software upgrades." (EP08)

Another asked the essential question from the clinician's perspective:

> "Does this achieve everything I want it to achieve without it being a mighty pain?" (EP05)

The success of implementing new technologies is tied as much to organisational fit as to technical excellence. One developer summarised the lesson clearly:

> "We try to build user-friendly systems... something very similar to what they have in their workflow currently... if not, we haven't built the system right." (EP06)

Sub-theme 2-4: Navigating Organisational Structures

Participants repeatedly emphasised that technological innovation in healthcare is filtered through complex organisational structures, procurement procedures, and institutional norms. Even highly promising technologies can stall if they are not aligned with administrative priorities, purchasing workflows, or the often opaque layers of internal approval.

One common thread was the disconnect between frontline needs and managerial decision-making. A participant reflected on this gap in the context of purchasing decisions and described how committees routinely overlook practical considerations such as user experience, device interactions, and environmental fit. They explained:

> "The decision-makers should look forward... there should be something in between the managerial purchasing group and the real frontline healthcare." (EP01)

Other participants pointed to the sheer complexity of navigating hospital bureaucracies. One robotics researcher described it as:

> "Layer upon layer of approvals and committees... You think you've got sign-off, then someone else pops up with another form." (EP13)

While these layers exist [for good reason—especially safety] this participant observed a frustrating paradox:

> "We talk about needing new tech to solve problems in hospitals, but then there's so many barriers to actually bring it in." (EP13)

In large institutions, innovation often has to bend to the system—not the other way around. One medtech founder commented:

> "Hospitals very purposely build this infrastructure to be cohesive... it's very difficult to move the behemoth towards you. You have to comply with their systems in order to be integrated." (EP09)

This dynamic means developers must not only design for clinical value but also anticipate administrative fit—from cybersecurity protocols to procurement pathways.

Participants with entrepreneurial or business-facing roles also spoke to the importance of existing relationships and distribution channels. One explained:

> "Distribution is really important... it helps with the hospital procurement system if they're already dealing with a company." (EP08)

Another added that systems under time and financial pressure have: "Limited tolerance for change." (EP08)

Participants also noted the importance of strong support from management. One aged care researcher credited their success in part to a facility where leadership was actively involved:

> "They didn't just sign off on it, they encouraged staff to come to demos... helped us coordinate with maintenance... little things like that make a big difference." (EP15)

In this case, the small size of the facility and flat communication lines helped reduce friction:

> "Management knew all the staff personally, decisions were quicker... it was just a quick chat with the care manager." (EP15)

Another participant pointed out that new technology can shift roles, routines, and expectations:

> "Suddenly you've got physios acting more like tech operators... it really can be some sort of organisational change, even on a very small scale, disguised as a device rollout." (EP12)

4.2.3 Theme 3: The Broader Landscape

While much of participants' discussion centred on the practical work of designing, developing, and implementing technologies, several also located these activities within a broader set of structural conditions that shape what is feasible in healthcare. Across accounts, they described their work and experience as constrained and directed by forces that operate beyond individual projects: public expectations, regulatory and governance arrangements, funding and reimbursement incentives, the surrounding technical and vendor ecosystem, and professional norms within health services.

Though often beyond the direct control of individual actors, these systems exert a formative influence on decision-making, design constraints, and the long-term viability of new technologies. These conditions can provide valuable information to development teams, helping them make better decisions about project direction, scope, pace, and risk tolerance. The sub-themes below summarise some of the main areas that emerged in the interviews.

Sub-theme 3-1: Regulatory Structures

One of the broader systemic factors participants consistently mentioned was regulation, which they described as a defining structural condition for technologies entering healthcare. Rather than acting as a final hurdle after technical development, regulatory requirements were described as ongoing constraints that shape system design, documentation practices, and the pace at which technologies can be trialled, deployed, and updated.

A recurring emphasis was that regulatory work is difficult to translate into the rational, cause–effect logic that many technical teams expect. One participant described regulatory compliance as complex and, at times, seemingly inconsistent from an engineering perspective:

> "It's very hard to explain it to people who are engineers, who are scientists, who have a very rational mindset, who have a very system approach to things where cause should have effects. The regulatory world doesn't work like that. It's a very bureaucratic and administrative work." (EP03)

Participants also described how regulatory constraints shape the *selection* of problems that teams choose to work on. In particular, EP04 noted that they deliberately scoped early work toward domains that avoided the full burden of healthcare regulation, because compliance timelines and approval uncertainty can slow iteration and threaten project viability:

> "We specifically chose areas where we wouldn't be burdened by healthcare regulation." (EP04)

As EP05 noted, teams may actively try to keep early prototypes outside the scope of "medical device" regulation because classification can trigger substantially heavier evidentiary and documentation requirements, longer approval timelines, and delays to eventual reimbursement: "You don't really want to be a medical device." (EP05)

Sub-theme 3-2: Governance, Funding, and Policy

Beyond formal regulation, participants described governance, funding, and policy as shaping the "operating environment" within which technologies are selected, financed, introduced, and sustained across health systems. In this broader sense, governance includes the institutions and decision-making arrangements that steer healthcare (e.g., ministries/Departments of Health, state or regional health authorities), as well as the policies and incentive structures they enact. Participants positioned these macro-level dynamics as highly consequential: even mature solutions can struggle to progress if they do not align with system priorities and purchasing logic.

Importantly, these are not always levers that individual development teams can directly change. However, they *do* shape what kinds of technologies (including HRC) are considered feasible, fundable, and legitimate in practice. For that reason, participants suggested that teams should be mindful of these structural constraints early, because they influence not only whether a technology is adopted, but also how it must be framed, evidenced, and scoped to fit within the health system.

A consistent message was that adoption decisions are often dominated by budgetary impact and reimbursement feasibility, sometimes outweighing considerations such as usability or design quality (EP01). Participants also discussed how funding constraints shape which innovations can realistically be tested and scaled, particularly in publicly funded settings. As one participant noted in relation to translational funding:

> "The downside of it is what we found was the funding that … is given for these … is just not enough." (EP01)

Several participants emphasised that reimbursement pathways and structures can be decisive, because they determine whether value can be "translated" into a sustainable business case. In practice, this means that clinical promise alone may be insufficient if the technology cannot be funded through existing reimbursement mechanisms or budget lines (EP05). Participants also highlighted how public-sector governance requirements (e.g., formal tender processes for high-cost purchases) can extend timelines and constrain what can be procured, even when there is clinical enthusiasm (EP02).

These system-level dynamics were described as especially consequential for robotic technologies, which tend to surface governance, funding, and policy constraints more sharply than smaller digital tools. Reflecting on their experience trialling rehabilitation robots, one founder noted that after the trial phase "the conversation shifts very quickly to budgets" and, crucially, to whether the robot has "a clear place" in the financial architecture of the system (EP12). In aged care contexts, participants described an additional tension between the kinds of benefits robots offer (e.g., easing workload) and the outcomes that funding models are designed to recognise, making it difficult to argue for robotics at system level when benefits are real but not easily convertible into existing reporting and funding priorities (EP15).

A participant further suggested that policy agendas influence which problems are prioritised and, by extension, which technologies are considered "worth" adopting. For example, workforce constraints in rehabilitation were described as a driver for considering automation and robotics:

> "[Rehabilitation] is extremely labour intensive and the demand keeps growing while the workforce doesn't, which is why robotics starts to look attractive." (EP12)

Sub-theme 3-3: Technology Landscape

Participants also located design and implementation decisions within a rapidly changing technology landscape, where developments outside healthcare can reshape what users expect inside it. In this view, technology "progress" becomes a reference point against which new healthcare tools are judged, influencing perceived legitimacy, usability expectations, and willingness to adopt.

A recurring example concerned user experience expectations shaped by consumer technologies. Several participants contrasted the intuitive, polished interfaces people use in everyday life with the fragmented and outdated systems they encounter in clinical settings. One clinician described contemporary hospital information systems in stark terms:

> "For instance, this computerized information systems, they are a disgrace to both technology and medicine. The things that are around at the moment are fragmented, poorly designed. They are like basically Windows 3.1 category software." (EP01)

This perceived gap was framed as consequential for adoption: as consumer technologies raise the baseline for what feels usable and "normal", health technologies that fall short can be experienced as unnecessarily burdensome. As another participant put it, systems need to be designed to feel as intuitive as everyday devices:

> "It needs to be made like an Apple phone ... and needs to be intuitive and relatively easy or otherwise, if it's not, no one will use it. It will sit in the corner because it takes too long for people to use it." (EP02)

AI was also frequently cited as a fast-moving general-purpose technology whose capabilities are becoming normalised outside healthcare. Participants suggested that rapid improvements in AI can amplify these expectation shifts: users may assume that automation, conversational interaction, and adaptive decision support should also be present in clinical tools.

> "When people get used to talking to systems like ChatGPT or Siri, clicking through ten screens in a hospital system just feels a waste of time." (EP14)

Taken together, these accounts suggest that keeping up with the broader technology landscape is not only about technical opportunity, but also about desirability and legitimacy: development teams are implicitly judged against the capabilities and interaction standards that users experience elsewhere. For emerging technologies such as HRC, this creates pressure to design systems that feel contemporary and intuitive, while still being realistic about integration, safety, and the constraints of clinical environments.

Sub-theme 3-4: Public Values and Cultural Norms

Participants also emphasised that public values and cultural norms shape what kinds of technologies are considered acceptable, trustworthy, and appropriate in healthcare, and that these expectations can vary substantially across settings. In this view, "public acceptance" is culturally situated, and it can influence which design choices are perceived as sensible (or risky) long before a technology reaches routine use.

Several participants suggested that exposure to robots in everyday life may differ across countries and can affect how people respond to robotic systems in public and clinical environments. One participant contrasted contexts where robots are already common in public-facing services with the likelihood of more sceptical or cautious reception in Australian healthcare settings:

> "What works socially in places like Singapore doesn't always translate. You can't assume that because people are comfortable with robots there, the same thing will hold in Australian hospitals or aged care settings." (EP12)

Participants also pointed out that the salience of specific concerns — such as privacy, data use, and surveillance — may differ across contexts, informed by local norms and regulatory/political histories. One participant reflected that privacy risks can feel more pronounced in Australia than in some other countries they had worked in:

> "From my experience… privacy concerns tend to come up much more strongly in Australia than in some other countries." (EP15)

For development teams, these accounts suggest an important implication: "good" HRC design may require contextual tailoring rather than assuming that solutions transfer unchanged across settings. In practice, cultural expectations can shape decisions about appearance and behaviour (e.g., how "social" a robot should be), appropriate degrees of autonomy, and what kinds of data collection are acceptable. More broadly, participants implied that aligning with local norms is part of building trust and legitimacy, as technologies that fit everyday expectations of dignity, privacy, and appropriate human contact are more likely to be accepted as supportive forms of care.

4.3 Discussion

Two points are important when interpreting these findings. First, participants generally drew on experiences with healthcare technologies more broadly, rather than on explicit HRC practice, as no participants with direct HRC experience were identified in the sample. As a result, the findings should be understood as transferable sociotechnical insights that may inform HRC, rather than as accounts of HRC implementation itself.

Second, the terminology used throughout this chapter reflects the diversity of technologies discussed in the interviews, including healthcare technologies, robotics, AI systems, and digital clinical systems. These broader terms are retained to remain faithful to participants' experiences, while the analysis focuses on implications relevant to HRC. Taken together, the findings suggest that the development and integration of HRC in healthcare should be understood as a sociotechnical challenge shaped by stakeholder relationships, situated work practices, and wider systemic conditions.

4.4 Conclusion

This chapter presented findings from exploratory semi-structured interviews conducted to address RQ1 and inform the early development of the proposed framework. The analysis identified sociotechnical insights considered transferable to HRC. Across the interviews, technology development and integration were consistently described as shaped by interdependent stakeholders, situated work practices, and broader systemic conditions. The next chapter turns to the quantitative component of the research, outlining the study design, measures, and analyses used to evaluate and extend the emerging framework.

Chapter 5

Acceptance Factors

This chapter addresses the second research question of the thesis: **RQ2: What factors influence the acceptance of HRC technologies in healthcare settings?** To answer this question, the chapter reports on a quantitative case study conducted at the University of Canberra Hospital. Rather than claiming universal determinants of HRC acceptance across healthcare, the study examines which factors appear most salient in one specific hospital context involving a proposed HRC application for the Rapid Response System.[1]

An acceptance study is particularly appropriate for HRC because based on findings presented in Chapter 4, it is shaped by how different stakeholders (e.g., clinicians, managers, and technical teams) interpret the technology's value, effort, safety, and fit with local work practices and accountability structures. Conducting the study in a concrete clinical context makes these constraints visible and measurable, enabling a grounded assessment of which factors appear most salient when HRC is evaluated against real operational demands.

The investigation builds on the technology acceptance literature reviewed in Section 2.3.3. Specifically, it applies UTAUT as a foundation for examining stakeholder perspectives. UTAUT provides a robust framework for analysing performance expectancy, effort expectancy, social influence, and facilitating conditions, but in the context of healthcare robotics and HRC these constructs may not be sufficient. To address this limitation, the study extends UTAUT by introducing three additional constructs that capture distinctive concerns in clinical practice: trust, perceived risk, and ethical concerns.

This study was conducted in an operational hospital ward to strengthen its ecological validity and address repeated calls for acceptability research to move outside the confines of laboratory-based studies (Ammenwerth 2019; David et al. 2022). In

[1] This study was undertaken as part of a broader collaborative project with Elizabeth Williams, Damith Herath, Grant Shaw, and Balaji Bikshandi; a paper based on this work is currently under review (see Publications and Contribution Statement).

doing so, it also responds directly to the gap identified in Section 2.2.2, namely the limited ecological validity of previous HRC research.

There are several elements that require clarification before turning to the case study itself. First, the Rapid Response System is outlined to show why it provides a relevant and demanding context for exploring HRC. Second, the proposed robotic system is introduced, demonstrating how HRC could support the RRS. Third, the acceptance framework underpinning the study is described, extending the UTAUT model to capture issues unique to healthcare. Finally, the methods, analysis, and results are presented.

5.1 Rapid Response Systems

Before presenting the study, it is necessary to clarify what an RRS is and why it serves as a relevant context for examining the acceptance of HRC. RRSs are hospital-wide safety mechanisms designed to identify and respond to early signs of patient deterioration. They typically consist of two main components: an afferent limb, which involves the detection of at-risk patients by bedside staff through early warning scores or clinical judgement, and an efferent limb, which involves the rapid deployment of a specialised response team to provide immediate assessment and intervention (Lyons et al. 2018).

The primary aim of an RRS is to prevent adverse outcomes such as cardiac arrest, unplanned intensive care admissions, or death, by ensuring timely escalation and intervention. In many hospitals, this involves mobilising multidisciplinary teams, including critical care physicians, nurses, and respiratory therapists, who work together to stabilise patients. The effectiveness of an RRS depends on reliable detection, clear communication, coordinated teamwork, and rapid access to resources (Lyons et al. 2018).

Given these characteristics, the RRS provides a particularly rich context for exploring HRC acceptance. HRC could assist with tasks that are time critical, mobile, and repetitive, provided that safety protocols and accountability structures remain transparent. For example, robots might support clinical staff by transporting equipment, fetching supplies, or providing monitoring assistance during periods of high demand. By relieving pressure on human responders, HRC could improve the consistency and efficiency of care escalation.

Despite this relevance, research on HRC within the RRS context remains scarce. Most existing studies of HRC in healthcare focus on rehabilitation, elder care, or surgical support. The RRS setting raises different challenges, since urgency, unpredictability, and interdisciplinary coordination play a central role. The novelty of this application and the lack of prior studies in RRS underscore the need for empirical evidence on acceptance.

Research on acceptance models in healthcare has expanded across multiple technologies; however, their relevance to HRC in Rapid Response Systems remains insufficiently examined. This creates a context-specific gap, as limited evidence is available on how such models operate within RRS environments. The unique interactional and operational dynamics associated with this form of integration remain insufficiently understood. Moreover, existing models have been criticised for giving inadequate attention to social, cultural, and organisational influences, despite their importance in healthcare environments (Ammenwerth 2019). This highlights the need for either the refinement of existing acceptance models or the development of new frameworks that can more effectively account for the contextual challenges and requirements involved in integrating HRC into Rapid Response Systems.

In the hospital context examined in this thesis, the RRS at the UCH is locally referred to as the *Hospital Emergency Response Officers* (HERO) team. Staff also use related terminology such as *MET* (Medical Emergency Team) and *Code Blue*, and activations may be described as a *HERO call*, *MET call*, or *Code Blue* depending on role and situation. For clarity, I use the term *RRS* when referring to the general hospital safety function, and *HERO* when referring to its local instantiation at UCH.

5.2 Research Model

The UTAUT model was used as the theoretical foundation for the research model in this study because of its suitability for organisational contexts. Its core constructs — performance expectancy, effort expectancy, social influence, and facilitating conditions — were incorporated as independent variables, with measurement items adapted from Venkatesh et al. (2003). Behavioural intention was specified as the dependent variable. To better align the model with the context of this study, three additional constructs were included: trust, ethical concerns, and perceived risk.

5.2.1 Operationalisation of Acceptance

In this study, *acceptance* is operationalised as *behavioural intention* to use or support the proposed robotic system. This follows a common approach in technology acceptance research, where behavioural intention is treated as the most proximal measurable indicator of whether individuals are willing to accept a new technology prior to full-scale implementation. Because the robotic system examined in this chapter was not yet deployed in routine clinical practice, actual use behaviour could not be observed directly. Behavioural intention therefore provided the most appropriate dependent variable for assessing anticipated acceptance in this *a priori* evaluation.

Accordingly, throughout this chapter, references to the "acceptance" of the proposed HRC system should be understood as stakeholders' stated intention or willingness to accept, support, or use the system if introduced into the RRS context at UCH.

5.2.2 Contextual Constructs

Trust Trust was incorporated into the study since it plays a crucial role in the acceptance of many technologies. In this study, trust is understood as the attitude that the robotic system and the actors surrounding it will help users achieve clinical goals in situations characterised by uncertainty and vulnerability. Previous studies across various domains highlight its strong influence on technology acceptance (Alharbi 2014; Dahlberg et al. 2003; Pavlou 2003; Liu and Tao 2022; Kamani et al. 2023). This issue is particularly relevant in intensive care, where healthcare professionals and patients rely on technology for critical clinical tasks. In such settings, trust in HRC is complex, involving not only confidence in the robot's reliability but also assurance in the environmental conditions that govern its use (Naneva et al. 2020), such as institutional protocols and safety safeguards. Trust may also vary between functional and social domains, depending on the nature of the task and the robot's role (Gaudiello et al. 2016). Accordingly, this study adopted a multidimensional view of trust, examining confidence in the robotic system, trust in operators, assurance in hospital operation and safety protocols, and trust in the developers of these robotic systems.

Ethical Concerns Ethical concerns were examined as a key issue in the use of HRC within RRS. In this study, they refer to concerns that the design, deployment, or operation of HRC may be inconsistent with accepted moral, professional, or patient-centred principles in healthcare. Interest in this topic has grown as interactive and collaborative robots have become increasingly relevant to care settings (de Graaf 2016). Healthcare robots introduce a range of ethical challenges, including implications for care, privacy, accountability, and fairness (Elendu et al. 2023; van Wynsberghe and Li 2019). Previous research also indicates that privacy and ethical concerns can significantly affect behavioural intentions toward robotic systems in healthcare (Kamani et al. 2023). Based on the existing literature (Elendu et al. 2023; Hung et al. 2022; Stahl and Coeckelbergh 2016; van Wynsberghe and Li 2019), seven relevant dimensions were identified: privacy, bias, consent, dependency, job displacement, responsibility, and transparency.

Perceived Risk Perceived risk was included as a key determinant of technology acceptance (Cocosila et al. 2009). For the purposes of this study, perceived risk is defined as the degree to which stakeholders perceive uncertainty in the use of HRC and the seriousness of the potential negative consequences associated with its implementation. In healthcare contexts, risk perceptions are particularly salient because of the direct implications for patient safety and wellbeing, especially in critical environments where tolerance for error is limited. Prior research has conceptualised perceived risk across multiple domains, including safety, psychological, and financial risks (Hsieh 2015). Accordingly, this study considered seven dimensions of perceived risk: operational, technical, cybersecurity, patient safety, privacy, compliance, and human factor risks.

5.2.3 Facilitating Conditions and Intention to Accept

In the original UTAUT model, facilitating conditions are more directly associated with use behaviour than with behavioural intention (Venkatesh et al. 2003). However, in this study they were modelled as a direct predictor of behavioural intention because the proposed HRC system had not yet been implemented, and actual use behaviour could therefore not be observed.

In an *a priori* evaluation of a safety-critical healthcare system, stakeholders may form their intention to accept the technology partly on the basis of whether they believe the organisational environment can support its safe and effective use. This includes perceptions of training, infrastructure, technical support, workflow integration, and governance. The direct path from facilitating conditions to behavioural intention is therefore treated here as a context-specific adaptation of UTAUT for an early-stage hospital evaluation.

5.2.4 Measurement Model and Hypotheses Development

Trust, ethical concerns, and perceived risk were treated as multidimensional constructs and measured formatively in the research model. Formative measures define a construct through its components, where the construct is understood as the combined result of its constituent dimensions (Hair et al. 2022). The UTAUT variables, however, were measured reflectively. Reflective measures assume that the construct gives rise to, and is represented by, its indicators (Hair et al. 2022), which is consistent with the standard approach in UTAUT research. Table 5.1 presents the constructs, their contextualised definitions, and the measurement model used for each. These definitions were tailored to the study context and account for the multi-stakeholder dimensions central to the research.

To examine the relationships among the constructs in the research model, seven hypotheses were formulated. Four draw on the UTAUT model, which has been applied extensively in both organisational and healthcare contexts. The other three extend the framework by addressing contextual constructs tailored to the needs of high-stakes healthcare environments. These hypotheses are listed below and illustrated in Figure 5.1.

- **H1**: Performance expectancy positively influences stakeholders' behavioural intention to accept the robotic system within Rapid Response Systems at UCH.
- **H2**: Effort expectancy positively influences stakeholders' behavioural intention to accept the robotic system within Rapid Response Systems at UCH.
- **H3**: Social influence positively influences stakeholders' behavioural intention to accept the robotic system within Rapid Response Systems at UCH.
- **H4**: Facilitating conditions positively influence stakeholders' behavioural intention to accept the robotic system within Rapid Response Systems at UCH.
- **H5**: Trust positively influences stakeholders' behavioural intention to accept the robotic system within Rapid Response Systems at UCH.
- **H6**: Perceived risk negatively influences stakeholders' behavioural intention to accept the robotic system within Rapid Response Systems at UCH.
- **H7**: Ethical concerns negatively influence stakeholders' behavioural intention to accept the robotic system within Rapid Response Systems at UCH.

Although the constructs in the model are inherently complex and interrelated, for analytical purposes I treated them as independent variables. This approach allowed

Table 5.1: Constructs, definitions, and measurement models used in the study

Construct	**Definition as applied in this study**	**Measurement model**
Performance Expectancy (PE)	The extent to which individuals believe that the proposed robotic system would improve the performance of RRS operations.	Reflective
Effort Expectancy (EE)	The extent to which individuals perceive the robotic system as easy to use within the hospital setting.	Reflective
Social Influence (SI)	The degree to which individuals believe that important people in their social network support the use of the robotic system.	Reflective
Facilitating Conditions (FC)	The extent to which stakeholders believe that adequate organisational resources are available to support the adoption of the robotic system.	Reflective
Trust (TRU)	Stakeholders' confidence that the robotic system, its developers, and the institutional measures in place can support safe, reliable, and effective operation.	Formative
Perceived Risks (PR)	Stakeholders' perception of the likelihood of risks arising from the use of the robotic system, including operational, technical, cybersecurity, patient safety, privacy, compliance, and human factor risks.	Formative
Ethical Concerns (EC)	Stakeholders' concerns about ethical issues related to the robotic system, including technical, operational, patient safety, cybersecurity, privacy, compliance, and human factor risks.	Formative
Behavioural Intention (BI)	Stakeholders' willingness or intention to accept the robotic system for use in UCH's RRS.	Reflective

for a structured assessment of their distinct effects, even while recognising that overlap and interaction occur in practice.

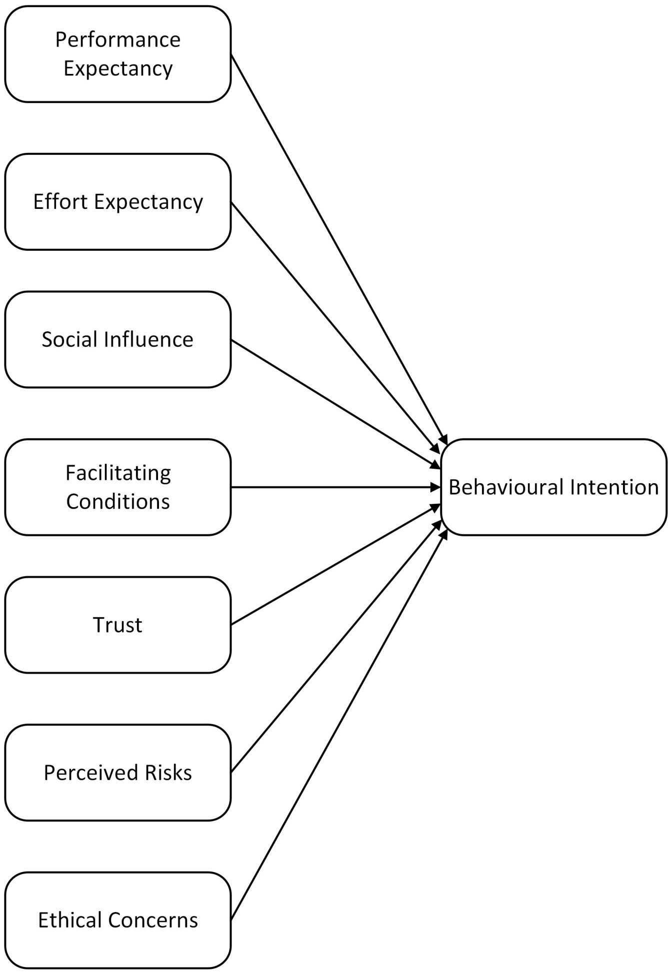

Figure 5.1: Hypothesised relationships among key constructs in the HRC acceptance model for RRS

5.3 Methods

This section summarises the methods specific to the acceptance factors study. The broader methodological foundations of the thesis are presented in Chapter 3. Here, the focus is on the study-specific elements required to interpret this case.

5.3.1 HRC system description

Because the study focused on *a priori* acceptability, participants were provided with written descriptions of the proposed robotic system and its capabilities. Technical terminology, including the term "human-robot collaboration", was avoided to improve comprehensibility. Instead, the description focused on the ways in which the robotic system could assist healthcare professionals in their work, explaining its intended purpose and functions in accessible language. As presented in the survey, the proposed system included the following features, functionalities, and design considerations:

- **Automated Navigation**: The robot can autonomously navigate to the required location, avoiding people and obstacles while adhering to hospital safety standards.

- **Compact Structure**: A sleek, compact design ensures the robot can move through hospital corridors and rooms with ease.

- **Visual User Interface**: A touch screen interface enables medical professionals to interact with the system, input commands, or retrieve patient data.

- **Voice Commands and Feedback**: Medical staff can provide voice instructions to control the robot and receive auditory confirmation or feedback, especially in situations where their hands are occupied.

- **Smart Documentation**: Artificial intelligence supports Electronic Health Records (EHR) by automatically updating patient records with the latest diagnostic data, reducing the burden of manual entry and improving efficiency.

- **Integrated Diagnostic Tools**: The trolley is equipped with tools to monitor vital signs such as heart rate, blood pressure, oxygen saturation, and temperature, providing real-time data to the medical team.

- **Inventory Management**: Sensors track stock levels, automatically notifying hospital systems when replenishment is required.

- **Automated Inventory Restocking**: When stock runs low, the robot can autonomously initiate restocking procedures. In addition to issuing alerts, it can be programmed to order replacements directly from the supply chain, streamlining the process.

- **Security & Privacy**: Patient data is encrypted, and the drug dispensation system secured to prevent unauthorised access.

- **Emergency Button**: In the event of malfunction or immediate need for human intervention, an accessible emergency button halts all robotic operations.

5.4 Results

5.4.1 Measurement model assessment

I assessed the constructs according to whether they were specified as reflective or formative. The reflective constructs, namely PE, EE, SI, FC, and BI, were evaluated using the criteria recommended by Hair et al. (Hair et al. 2022), including indicator reliability, internal consistency reliability, convergent validity, and discriminant validity. Tables 5.2 and 5.3 summarise the assessment criteria and present the corresponding results.

The assessment of the formative constructs, TRU, PR, and EC, followed the procedure recommended by Hanafiah (Hanafiah 2020). This procedure included evaluating indicator collinearity, the significance and relevance of outer weights, and indicator loadings. Collinearity was assessed using the Variance Inflation Factor (VIF), with all values falling below the recommended threshold of 5. The outer weights were then tested for significance, with sixteen indicators showing non-significant weights. Further inspection of their loadings showed that only one perceived risk indicator, PR2, had both a non-significant loading and a loading below 0.5. Given its conceptual overlap with other perceived risk indicators, PR2 was removed from the analysis. Detailed results of the measurement model assessment are provided in Chapter D.

Table 5.2: Assessment criteria and recommended thresholds for reflective measurement models based on (Hair et al. 2022)

Criterion	**Description**	**Threshold**
Indicator Reliability	The extent to which each indicator adequately represents its underlying construct.	Outer loadings for each item > 0.70
Internal Consistency Reliability	The degree to which indicators of the same construct are consistently related to one another.	Cronbach's $\alpha > 0.70$
Convergent Validity	The extent to which a construct explains the variance of its associated indicators.	Average Variance Extracted (AVE) > 0.50
Discriminant Validity	The extent to which a construct is empirically distinct from other constructs in the model.	Heterotrait-Monotrait (HTMT) ratio for each item $<$ 0.85

Table 5.3: Construct assessment results

Criterion	PE	EE	SI	FC	BI
Indicator Reliability	Satisfied	Satisfied	Satisfied	Satisfied	Satisfied
Internal Consistency Reliability	0.94	0.86	0.91	0.71	0.82
Convergent Validity	0.76	0.64	0.85	0.77	0.85
Discriminant Validity	Satisfied	Satisfied	Satisfied	Satisfied	Satisfied

5.4.2 Demographic characteristics of participants

The demographic characteristics of the participants are presented in Tables 5.4 and 5.5. The study included 74 participants. Their distribution across age and gender groups broadly reflected the hospital's overall demographic profile. Stakeholder representation comprised UCH employees (60%) and patients and visitors (37%). Although not evenly balanced, this distribution aligns with the stakeholders' likely engagement with RRS.

Familiarity with RRS was generally low: 29% of participants had never encountered RRS prior to the survey, and 40% reported only some familiarity. This result was anticipated, given how RRS is currently deployed in the hospital. Two UCH employee subgroups—Doctors and Medical Staff, and Hospital Administrative and Support Staff—were notably underrepresented. This underrepresentation likely reflects workload constraints and highlights the need for alternative engagement strategies in future research.

5.4.3 Hypothesis Testing

The research model was tested by examining the relationships between the independent variables, PE, EE, SI, FC, TRU, PR, and EC, and the dependent variable, BI. The significance of each path coefficient was assessed through bootstrapping with 5,000 sub-samples. A path was considered statistically significant when the t-value was greater than 1.96 and the p-value was less than 0.05 (Hair et al. 2022). Table 5.6 presents the direct path coefficients, t-values, and p-values for each hypothesis.

The analysis revealed that behavioural intention to accept the robotic system was significantly shaped by performance expectancy, trust, perceived risk, and ethical concerns. Among the positive predictors, performance expectancy had a notable influence, suggesting that participants were more inclined to accept the system when

Table 5.4: Demographic characteristics of study participants – All participants (n=74)

Characteristics (All Participants)	
Age groups	**n (%)**
18–24	3 (4%)
25–34	19 (25%)
35–44	18 (24%)
45–54	16 (21%)
55–64	7 (9%)
65 or older	11 (14%)
Gender	**n (%)**
Female	46 (62%)
Male	27 (36%)
Prefer not to say	1 (1%)
Role	**n (%)**
UCH Employee or Associate	45 (60%)
Patient / Patient Advocate	19 (25%)
Visitor	9 (12%)
Other	1 (1%)
RRS familiarity	**n (%)**
Never heard of or encountered RRS before this survey	22 (29%)
Some familiarity, but do not fully understand all aspects	30 (40%)
Heard of RRS, but do not know much about their function	11 (14%)
Very familiar with RRS and understand how they operate	11 (14%)
Experience with different technologies (1 = None to 5 = Extensive)	**mean (s.d.)**
General Technological Systems	4.04 (1.04)
Healthcare Technology	3.15 (1.46)
AI-enabled Systems	2.55 (1.16)
AI-enabled Systems in Healthcare	1.5 (0.85)
Robotic Technology in General	1.96 (1.07)
Robotic Technology in Healthcare	1.34 (0.86)

Table 5.5: Demographic characteristics of subgroups – UCH staff (n=45) and visitors/patients (n=29).

Characteristics (Subgroups)	
Staff Role (UCH staff only, n=45)	**n (%)**
Allied Health Professionals	33 (73%)
Doctors and Medical Staff	1 (2%)
Hospital Support and Administrative Staff	1 (2%)
Nursing Staff	8 (18%)
Other	2 (4%)
RRS Membership (UCH staff only, n=45)	**n (%)**
No, never been a member	38 (84%)
Yes, currently a member	6 (13%)
Yes, previously a member but not currently	1 (2%)
Years of Work at UCH (UCH staff only, n=45)	**n (%)**
1–3 years	13 (29%)
4–6 years	24 (53%)
Less than 1 year	3 (7%)
More than 7 years	5 (11%)
Visit Frequency (Visitors and patients only, n=29)	**n (%)**
Multiple times a month or more often	13 (45%)
Occasionally	7 (24%)
Only once	3 (10%)
Regularly but infrequently	5 (17%)
Several times a year	1 (3%)

Table 5.6: Direct paths and bootstrapping results

Hypothesis		**Direct path coefficient (β)**	**t-value**	**p-value**	**Supported?**
H1	PE $\rightarrow$ BI	0.28	2.98	0.003	Yes
H2	EE $\rightarrow$ BI	0.04	0.63	0.530	No
H3	SI $\rightarrow$ BI	0.11	1.17	0.241	No
H4	FC $\rightarrow$ BI	-0.01	0.18	0.857	No
H5	TRU $\rightarrow$ BI	0.21	2.40	0.016	Yes
H6	PR $\rightarrow$ BI	-0.20	2.37	0.018	Yes
H7	EC $\rightarrow$ BI	-0.27	2.61	0.009	Yes

they perceived it as beneficial for improving the effectiveness of RRS activities (β = 0.28, t = 2.98, p = 0.003). Trust was also positively associated with acceptance, indicating that confidence in the robot's dependability, the supporting institutional arrangements, and the expertise of operators and developers contributed to greater willingness to adopt the system (β = 0.21, t = 2.40, p = 0.016). Conversely, perceived risk was negatively related to behavioural intention, showing that concerns about operational reliability, technical limitations, and privacy could discourage acceptance (β = -0.20, t = 2.37, p = 0.018). Ethical concerns also had a significant negative association with acceptance, reinforcing the need to address issues such as privacy protection, algorithmic bias, and transparency in the design and implementation of the system (β = -0.27, t = 2.61, p = 0.009).

5.5 Discussion

This study examined factors influencing the behavioural intention to accept HRC in the Rapid Response System at UCH, using UTAUT as a baseline and extending it with three healthcare-relevant constructs: trust, perceived risk, and ethical concerns. As an exploratory investigation into a high-stakes and time-critical hospital function, it provides an empirical view of which considerations most strongly shape stakeholders' intention to accept an HRC system.

The hypothesis testing suggests that behavioural intention to accept in this context is driven less by generic organisational predictors and more by whether stakeholders judge the system to be (i) useful for core work objectives and (ii) legitimate and safe within healthcare accountability structures. Performance expectancy was the only supported UTAUT construct, indicating that stakeholders prioritise demonstrable contribution to RRS performance. In contrast, effort expectancy, social influence, and facilitating conditions were not significant, which may reflect the RRS environment's urgency, role coordination, and limited tolerance for added complexity.

The significant effects of trust, perceived risk, and ethical concerns indicate that acceptance judgements are tightly coupled to confidence in reliable operation, institutional safeguards, and the acceptability of data use and responsibility arrangements (Ammenwerth 2019; Shachak et al. 2019). In the proposed design, the robot was envisioned to take on duties that can be perceived as higher risk (e.g., documentation support and information handling), which plausibly amplifies concerns about cybersecurity, privacy, accountability, and error consequences. These findings align with prior observations that clinicians may support robotic assistance for routine tasks while remaining cautious about more consequential roles (Song et al. 2025), and that human and organisational factors are central to safety and effectiveness in collaborative clinical technology use (Catchpole et al. 2024).

Although this study provides an answer to RQ2, it does so within a specific empirical context rather than at the level of universal generalisation. This is important because behavioural intention to accept or the acceptance of HRC in healthcare is not fixed but shaped by context, a point consistent with the findings presented in Chapter 4. The study therefore identifies the factors influencing acceptance in this particular case, while also underscoring the need for further research across diverse healthcare settings.

5.6 Conclusion

This chapter identified which factors most strongly influenced stakeholders' intention to accept a proposed HRC system in a hospital RRS context. The results highlight the central role of perceived usefulness alongside trust-, risk-, and ethics-related considerations, suggesting that acceptance is shaped by both performance expectations and the perceived legitimacy of the technology within safety-critical clinical environments.

In Chapter 6, these findings are integrated with the qualitative insights from Chapter 4 to inform the development of the thesis framework. In particular, the framework draws on the acceptance-related constructs identified here to specify decision points and design considerations for anticipating stakeholder concerns, evidencing value, and managing risk and ethical acceptability during HRC development and integration.

Chapter 6

Framework Development: STEER-H

To synthesise the patterns and insights from the exploratory interviews (Chapter 4) and the acceptance study (Chapter 5), this chapter develops a sociotechnical framework that connects the different dimensions of technology integration in healthcare. I refer to this framework as **STEER-H** (*Sociotechnical Engineering for Effective Robotics in Healthcare*).

The framework structure was guided primarily by the three qualitative themes reported in Chapter 4 (*An Interwoven Stakeholder Ecosystem*; *Context-Aware Design and Development*; *The Broader Landscape*). The quantitative findings in Chapter 5 were then used to refine and substantiate the stakeholder dimension of the framework rather than to generate additional themes.

Methodologically, this framework is the thesis artefact developed through the Design Science Research approach described in Chapter 3. In particular, the framework development reflects the DSRM design-and-development activity.

6.1 STEER-H

Nilsen describes a framework as a structured way to organise ideas, concepts, and relationships in order to describe a phenomenon (2015). Unlike a theory, a framework does not explain or predict outcomes. Instead, it provides a set of categories or connections that help make sense of complex realities. This makes it a suitable approach for representing the layered and interconnected nature of healthcare systems.

In addition to the insights generated from the empirical studies (Chapters 4 and 5), I draw on concepts and guidelines from sociotechnical systems theory (Section 2.3.1), technology acceptance theory (Section 2.3.3), and the healthcare robotics literature

(Section 2.4) to inform the conceptual framing and structure of the framework.

The framework maps how people, organisations, and broader structural forces interact to influence the introduction and use of HRC systems in healthcare. It does not offer a step-by-step guide. Rather, it provides an analytic lens for understanding how multiple factors operate together, helping developers and decision-makers identify where attention or support may be needed.

I named the framework *Sociotechnical Engineering for Effective Robotics in Healthcare* to reflect its role in guiding understanding and decision-making around the development and integration of HRC technologies in healthcare. Here, "effective" refers to the extent to which HRC technologies can be meaningfully integrated into healthcare practice in ways that are context-sensitive, accepted by stakeholders, and sustained over time. In alignment with Research Question 3 (RQ3) — namely, how insights into the development, introduction, and acceptance of HRC technologies can inform practical guidance for their design and integration in healthcare — STEER-H is intended as a practice-oriented framework that translates empirical and theoretical insights into a structured basis for reflection, design, and integration. It is therefore best understood not as a predictive or prescriptive model, but as an analytic framework for examining the sociotechnical conditions surrounding HRC development and integration in healthcare.

The framework consists of three interconnected layers (Figure 6.1):

- **The Stakeholder Layer**: Centred on individuals and groups who directly engage with the technology, as well as those indirectly affected by it.
- **The Institutional Layer**: Representing the organisational and environmental conditions of the healthcare work system that shape (and sometimes constrain) the integration of HRC systems.
- **The Ecosystem Layer**: Encompassing wider regulatory, economic, and societal forces that shape the development, evaluation, diffusion, and long-term sustainment of HRC systems.

6.2 The Stakeholder Layer

At the centre of the framework are the people who interact with the technology — clinicians, patients, managers, allied health professionals, and others. Their experiences, interpretations, and choices influence whether an HRC system is adopted, adapted, or rejected in practice.

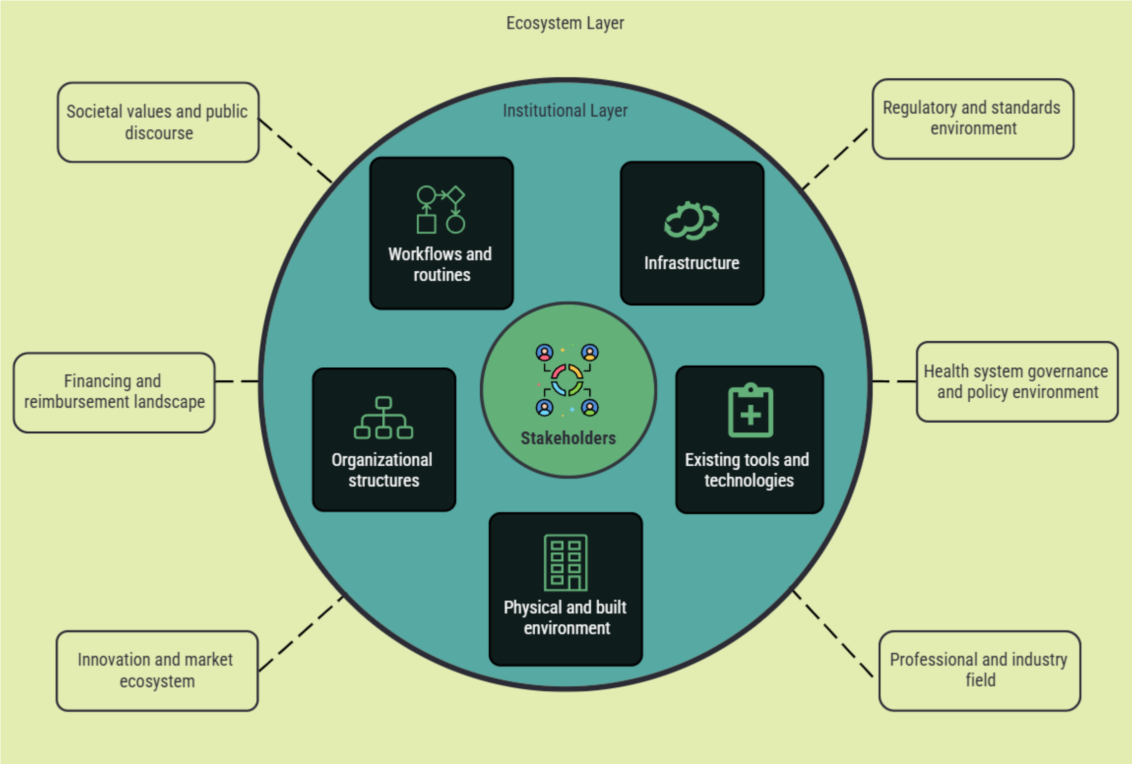

Figure 6.1: STEER-H (*Sociotechnical Engineering for Effective Robotics in Healthcare*): the sociotechnical framework developed in this thesis, showing three interacting layers that shape HRC integration in healthcare.

This layer reflects perspectives such as user-centred design and systems thinking, both of which emphasise that technological change is shaped by the people situated around it. In STEER-H, the stakeholder layer foregrounds the human dimension of HRC integration by focusing on who is involved, what matters to them, and how their perspectives shape implementation outcomes.

6.2.1 Understanding Stakeholders

A first step in this layer is identifying who the relevant stakeholders are. These include not only direct users of the technology, but also those indirectly affected by its introduction or involved in decisions about its adoption, use, and evaluation. In healthcare, this often means considering a broad network of actors rather than a single end-user group.

There are several established approaches to stakeholder identification in the literature. For example, stakeholder analysis has been used to identify and characterise actors in terms of their interests, influence, and potential roles within a system (Brugha and Varvasovszky 2000). In STEER-H, the key point is that stakeholder identification should move beyond a narrow view of “the user” and instead recognise the interdependent set of actors who shape the success or failure of HRC integration.

However, identifying stakeholders is only the starting point. Equally important is understanding what matters to them — including their needs, expectations, values, concerns, and day-to-day realities. Within this framework, stakeholders are not treated simply as groups to be consulted, but as a primary means of understanding what is actually needed for HRC technologies to work in practice. Their perspectives help reveal which problems are worth addressing, what kinds of support or change may be required, and where misalignments between technological possibilities and healthcare realities may arise.

This connects directly to Theme 1 (*An Interwoven Stakeholder Ecosystem*) in Chapter 4, which highlighted that successful integration depends on aligning technologies not only with user needs, but also with the broader network of stakeholders who influence adoption and use. From this perspective, understanding stakeholders is a central way of determining what meaningful design, development, and integration should involve in a given healthcare context.

This emphasis is also supported by sociotechnical thinking, which treats design as a collaborative process involving multiple actors. As noted in Section 2.3.1, Clegg (Clegg 2000) argues that sociotechnical principles are intended to guide reflection and negotiation among those involved in design.

It also resonates with Hollnagel’s distinction between *work-as-imagined* and *work-as-done* (Hollnagel 2015). Whereas work-as-imagined reflects how work is expected, prescribed, or planned to occur, work-as-done refers to how it is actually carried out in practice. Attending to stakeholder perspectives is one way of making this distinction visible, as stakeholders can reveal how everyday work is adapted, coordinated, and negotiated under real clinical conditions.

6.2.2 Acceptance as a Core Concept

Within STEER-H, the stakeholder layer extends beyond identifying stakeholder groups or eliciting functional requirements. It also foregrounds acceptance, that is, how individuals and groups interpret a technology and judge whether it aligns with their values, routines, roles, and professional practices.

This emphasis draws on technology acceptance research (e.g., Davis 1989; Venkatesh et al. 2003) as well as the findings discussed in Chapter 5. In STEER-H, acceptance is not treated simply as an outcome to be measured after implementation. Rather, it is used as an analytic lens for identifying stakeholder-level design and integration considerations that may shape whether an HRC system is perceived as appropriate and desirable in practice. In this sense, acceptance helps surface the factors that should inform the design, development, and integration of HRC technologies.

For example, if ethical concerns are identified as a factor influencing the acceptance of a particular stakeholder group in a specific context, then these concerns should not be treated as peripheral. Instead, they become a design and integration priority. This may require the development and implementation team to adopt specific responses, such as improving transparency around the system's role and capabilities, clarifying accountability, strengthening privacy and safety safeguards, or creating opportunities for stakeholder consultation and feedback. In this way, acceptance is used not only to understand stakeholder responses but also to guide practical decisions about how HRC technologies should be designed and introduced in healthcare settings.

6.2.3 Key Stakeholder Considerations

The data from Theme 1 (*An Interwoven Stakeholder Ecosystem*) further highlights several considerations that are central to the stakeholder layer of STEER-H.

- **Stakeholders are multiple and interdependent**: HRC integration depends on a broad network of actors whose roles, interests, and responsibilities are interconnected.
- **Collaboration across silos is essential**: Effective design and integration require coordination across clinical, technical, managerial, commercial, and regulatory domains. No single discipline can adequately define needs or drive implementation in isolation.
- **Stakeholder engagement should begin early**: Early and inclusive engagement helps identify needs, constraints, and concerns before they become barriers later in the development or implementation process.
- **Relevant stakeholders may emerge over time**: Some actors only become visible once implementation begins, particularly those connected to governance, risk, infrastructure, procurement, or operational oversight. Stakeholder identification should therefore remain iterative rather than fixed at the outset.
- **Stakeholders may hold competing priorities**: Different groups may judge the same technology through different lenses, including clinical value, workflow

impact, cost, evidence, usability, or strategic benefit. These differences require negotiation rather than assuming consensus.

6.3 The Institutional Layer

Surrounding the stakeholder layer is the institutional layer, which represents the organisational systems, infrastructures, and environments that shape how technologies are used in practice.

In the interview data, these institutional dimensions closely mirror the sub-themes of Theme 2 (*Context-Aware Design and Development*) in Chapter 4. Participants described how effective integration depends on a technology's ability to fit with existing workflows, tools, spaces, and organisational structures. I define the institutional layer through five key components:

- **Workflows and routines**: The clinical and administrative processes that organise everyday work, including the established patterns of care with which new technologies must align rather than disrupt.
- **Infrastructure**: The digital, technical, and logistical supports that enable or constrain system performance, particularly where compatibility and interoperability with existing systems are required for reliable operation.
- **Organisational structure**: The hierarchies, communication channels, and governance arrangements that distribute authority and accountability, and that shape whether a technology progresses from prototype to implementation.
- **Physical and built environment**: The spatial, sensory, and ergonomic conditions that influence how technologies are deployed and whether they can be used safely and efficiently in practice.
- **Existing tools and technologies**: The legacy systems and devices with which new technologies must integrate, coexist, or which they may replace, including the interoperability challenges that can create duplication or technical fragmentation.

This layer highlights that institutional fit is as important as user perception. It bridges the micro-level experiences of stakeholders with the organisational and management-level structures that either enable or constrain integration. As reflected in Theme 2 of Chapter 4, institutions do not simply host technologies — they actively shape how those technologies are developed, implemented, and sustained within healthcare practice.

This part of the framework was informed by work system perspectives in healthcare, particularly Carayon's Work System Model (2006), in recognising the different elements of an organisation.

For developers and system integrators, this means paying close attention to institutional factors early in the design process. They must move beyond creating technically capable tools to ensuring that their systems align with existing workflows, infrastructure, and governance structures. This involves working collaboratively with healthcare organisations to map routines, identify points of friction, and co-design solutions that fit the spatial and operational conditions of real care environments.

6.4 The Ecosystem Layer

The outermost layer of STEER-H is the ecosystem layer. Whereas the institutional layer focuses on the organisational conditions within which HRC technologies are introduced and used, the ecosystem layer captures the broader structural environment beyond the boundaries of any single organisation. It refers to the system-level, sector-wide, and societal forces that shape which technologies are developed, how they are evaluated, what forms of adoption are supported, and whether integration can be sustained over time.

This layer is informed by Theme 3 (*The Broader Landscape*) in Chapter 4. In the interview data, participants described how HRC development and integration are influenced not only by local organisational factors, but also by wider conditions such as policy priorities, regulatory pathways, funding arrangements, professional expectations, and public values. These influences operate across organisations and often remain outside the control of individual teams; yet, they strongly shape what is possible within healthcare settings.

The ecosystem layer is defined through six interrelated elements:

- **Health system governance and policy environment**: The broader policy, governance, and strategic structures that shape how innovation is prioritised, supported, and regulated across the healthcare system. These system-level arrangements influence which forms of HRC receive legitimacy, investment, and institutional backing.
- **Regulatory and standards environment**: The approval pathways, compliance requirements, safety expectations, and evidentiary standards that govern the development, validation, and deployment of HRC technologies. These

structures are essential for accountability and safety, but they also shape the pace and direction of innovation.

- **Financing and reimbursement landscape**: The wider economic arrangements that determine how HRC technologies are funded, procured, reimbursed, and sustained. This includes not only research and development funding, but also the financial logics that influence whether technologies can move beyond pilot implementation into routine use.
- **Professional and industry field**: The wider network of professional bodies, industry actors, standards communities, and sectoral relationships that shape expectations around good practice, legitimacy, and role boundaries. These field-level dynamics influence how HRC technologies are interpreted, promoted, and contested across healthcare and technology domains.
- **Societal values and public discourse**: The broader cultural expectations, ethical debates, and public narratives that shape what kinds of technological intervention are considered appropriate, desirable, or concerning in healthcare. These societal influences affect public trust, political support, and the legitimacy of particular applications of HRC.
- **Innovation and market ecosystem**: The wider landscape of technological development, commercial activity, vendor relationships, interoperability expectations, and competing innovations that shape what is technically and economically feasible. HRC technologies do not emerge in isolation, but within a changing ecosystem of platforms, suppliers, infrastructures, and market pressures.

These elements together illustrate that innovation in healthcare is never an isolated technical exercise and is embedded in a broader ecosystem of policies, expectations, and wider structural conditions. This layer was also shaped by broader implementation scholarship, particularly the ecosystem domain of Greenhalgh's NASSS framework (Greenhalgh et al. 2017).

For developers and integration teams, this means looking beyond the immediate implementation site. In practice, this may involve considering reimbursement pathways, regulatory requirements, policy priorities, professional endorsement, public legitimacy, and the wider market conditions that will influence whether an HRC system can move beyond development or pilot testing into sustained use. The ecosystem layer thus highlights that what appears to be a local implementation challenge is often shaped by forces operating far beyond the organisation itself.

6.5 Discussion

Although STEER-H is presented as three distinct layers, these layers are not independent. Rather, they are mutually shaping and continuously interact with one another. Stakeholder needs, perceptions, and practices are influenced by institutional conditions such as workflows, infrastructure, and governance, while those institutional conditions are themselves shaped by wider ecosystem forces such as regulation, funding, professional norms, and public expectations. At the same time, challenges experienced by stakeholders in practice can feed back into organisational priorities and, over time, influence broader policy, professional, or market discussions. STEER-H should therefore be understood not as three separate domains, but as an interconnected system in which change at one layer can create effects across the others.

While these interactions are central to the framework, STEER-H does not attempt to visually specify every possible relationship between its components. This was a deliberate design choice. In complex healthcare settings, the relationships between stakeholder, institutional, and ecosystem factors are dynamic, context-dependent, and likely to vary across technologies, clinical settings, organisations, and stages of adoption. Mapping all possible interactions would risk making the framework overly complex and less usable for its intended purpose. It could also imply a level of fixed causality or completeness that would be inconsistent with the sociotechnical framing of this thesis. Instead, STEER-H is intended to make the main layers and domains of concern visible while encouraging users to examine the specific interactions, dependencies, and feedback loops that are most relevant in their own implementation context.

This interconnected view also helps position STEER-H in relation to the multilevel challenges identified in the healthcare robotics literature reviewed in Section 2.4. Broadly, the stakeholder, institutional, and ecosystem layers correspond to the micro-, meso-, and macro-level concerns discussed there. The stakeholder layer captures issues of perception, acceptance, trust, and the lived experience of care; the institutional layer reflects the organisational and work-system conditions that shape implementation; and the ecosystem layer addresses the wider structural influences of policy, regulation, funding, professional norms, and public legitimacy.

The contribution of STEER-H, however, is not simply to reproduce these levels. Rather, it reframes them as part of an interconnected sociotechnical system and encourages the challenges that arise during HRC development and integration to be understood relationally rather than in isolation. In practice, this means that what appears to be a stakeholder-level issue, such as low acceptance or resistance, may also reflect institutional conditions such as poor workflow fit, limited infrastructure, or inadequate organisational support, as well as ecosystem influences such as regulatory uncertainty, weak reimbursement pathways, or broader public concerns.

Seen in this way, STEER-H offers an integrated and practice-oriented basis for understanding HRC development and integration in healthcare.

6.6 Conclusion

This chapter developed STEER-H as a sociotechnical framework for understanding HRC development and integration in healthcare. By structuring the findings across stakeholder, institutional, and ecosystem layers, it provides an analytic lens for examining how challenges and enabling conditions emerge across interacting levels. The following chapter uses Case Study 1 to demonstrate and evaluate the framework in practice.

Chapter 7

Case Study 1: HRC for Rapid Response System

This chapter presents a qualitative case study used to *demonstrate and evaluate* the STEER-H framework developed in Chapter 6. It focuses on one design opportunity: using HRC to support equipment mobilisation during rapid response activations at the University of Canberra Hospital.[1]

The case centres on the UCH's RRS (the same context as Chapter 5), locally referred to as the **HERO** team (Hospital Emergency Response Officers). This case study drew on qualitative evidence, including in situ observations of HERO-related workflows, semi-structured interviews with clinical and operational stakeholders, and a review of relevant hospital documents describing RRS policies and procedures. Data collection was conducted over one week on site at the UCH. Full details of UCH and broader methodological considerations are described in Chapter 3.

The purpose of this chapter is not to provide a comprehensive empirical account of the broader project. Rather, the case study is used as an analytic vehicle for demonstrating how STEER-H can be applied in practice and for evaluating its usefulness in structuring and interpreting a sociotechnical HRC design problem. Accordingly, only findings directly relevant to framework demonstration and evaluation are presented.

7.1 Case Context

This case study began as a collaborative design exploration. Together with my collaborators, I entered the project with an existing concept: a robotic trolley with a range of AI-enabled features to reduce physical strain and improve efficiency,

[1] This case study was undertaken as part of a broader collaborative project with Elizabeth Williams, Damith Herath, Grant Shaw, and Balaji Bikshandi.

Figure 7.1: Existing HERO equipment trolley used at the University of Canberra Hospital. The trolley is used to transport emergency response equipment required during rapid response activations.

accuracy, and workflow during HERO operations, consistent with the goal described in Chapter 5. The existing HERO equipment trolley used at UCH is shown in Figure 7.1.

The team included the same experts as the acceptance case study: myself, two supervisors, one intensive care specialist, and one department manager from UCH. The initial idea for this project came from the intensive care specialist, who identified two persistent challenges in acute hospitals: the high rate of RRS activations and the burden of moving the trolley and associated equipment. At the same time, emerging technologies offered potential support options, such as wearables for automatic activation and smart features such as automated stock management. These considerations shaped the model proposed in the acceptance study (Section 5.3.1). That proposal reflected how the team initially viewed the work, or, in Hollnagel's terms, *work-as-imagined* (Hollnagel 2015).

7.2 Overview of The Study

This case study involved 11 participants: 3 from medical roles and 8 from nursing roles. The nursing participants included Clinical Development Nurses (CDNs), Clinical Nurse Educators (CNEs), Clinical Nursing Consultants (CNCs), and Registered Nurses (RNs). The medical participants held senior medical and clinical leadership roles in rehabilitation medicine. Participant details are summarised in Table 7.1.

Table 7.1: Participant groups and IDs for Case Study 1.

Role group	**Participant IDs**
Nursing stakeholders	C1P01, C1P02, C1P03, C1P04, C1P05, C1P06, C1P09, C1P11
Medical stakeholders	C1P07, C1P08, C1P10

Analysis proceeded in two stages. First, the interview, observation, and document data were reviewed inductively to develop an account of how HERO-related work was performed in practice, with particular attention to the mobilisation, use, checking, and replenishment of equipment during rapid response events. The codebook is included in Chapter E, organised by code category, code, and description. Second, these findings were interpreted deductively through the STEER-H framework developed in Chapter 6. This enabled the case to be examined across three interacting layers: stakeholder, institutional, and ecosystem.

7.3 Findings from the Case

Three broad findings emerged from the case study:

1. HERO work was consistently described as fast-moving, cognitively demanding, and highly dependent on timely access to functioning equipment and up-to-date information.
2. Support for the initial idea of a robotic trolley was common, but was typically expressed in relation to a broader support system involving stock management, workflow prompting, documentation support, and equipment tracking, rather than autonomous transport alone.
3. The challenges and opportunities identified in the case spanned all three STEER-H layers, indicating that the design opportunity could not be understood solely in terms of usability or technical feasibility.

The following sections elaborate these findings through the STEER-H framework, showing how stakeholder, institutional, and ecosystem factors shaped both the perceived value of the proposed system and the practical constraints on its implementation.

7.4 Demonstrating STEER-H Through the Case

The case study findings were organised through the three layers of STEER-H: stakeholder, institutional, and ecosystem. This analysis demonstrates how the framework can be used to move from a general design idea toward a more grounded understanding of the sociotechnical conditions shaping the feasibility and value of HRC in this setting. Applying STEER-H to this case was helpful because it made visible multiple factors at each layer of the system.

7.4.1 Stakeholder layer

The stakeholder layer draws attention to how different actors perceived the design opportunity, what needs they prioritised, and what concerns shaped the legitimacy of the proposed system.

Across both nursing and medical participants, attitudes toward innovation were generally positive. Many participants framed AI and related technologies as a natural or inevitable progression in healthcare practice.

> "The evolution of healthcare has changed, and it is certainly becoming more digitalized and electronic. So, I see it as part of that evolution" (C1P01)

Several participants were openly enthusiastic about the potential benefits of automation for reducing burden and improving efficiency (C1P04, C1P05, C1P10, C1P11). However, this support was conditional. Participants did not advocate for replacing clinicians; rather, they emphasised technologies that would support human decision-making, reduce repetitive tasks, and make critical information more visible at the point of care. For example, one medical participant specifically described AI as useful in an “opt-in” decision support role rather than as a replacement for clinicians.

> "I don’t think anyone’s going to want something that’s going to be substituting for the role of a doctor in terms of making decisions... whatever

> we introduce will have to exist in parallel" (C1P08)

The stakeholder data also showed that different groups emphasised different needs. Nursing participants frequently focused on the physical and operational burdens of HERO work, such as difficulty accessing heavy equipment (C1P02), locating borrowed or powered devices (C1P05), tracking stock and expiry dates (C1P09), or dealing with non-functioning ward hardware such as printers, thermometers, and Computer on Wheels (COW) (C1P01, C1P03, C1P04). These participants tended to value features that reduced task load, such as automated stock alerts, digital tracking, voice-activated functions, and integrated cognitive aids (C1P01, C1P02, C1P04, C1P09, C1P11).

> "Anything that can help them not have to do a thousand things at once, essentially, is great. I think they'd be very open to it" (C1P05)

> "I genuinely believe that a lot of people would embrace that change... In fact, it might enable us to provide more person-centred and sensitive care because there are certain tasks that have been taken care of" (C1P11)

Medical participants, by contrast, more often emphasised diagnostic support, deterioration recognition, documentation, and preserving oversight of team coordination (C1P07, C1P08, C1P10).

Several recurrent concerns shaped stakeholder acceptance. The first was *trust in reliability*. Participants were interested in autonomous navigation, automated stock checking, and AI prompts, but repeatedly raised concerns about technical glitches, maintenance, and whether systems would function accurately under pressure (C1P01, C1P02, C1P03, C1P05, C1P07). The second was *workload sensitivity*. Participants were clear that they would resist systems that added administrative burden, slowed them down, or required extensive additional interaction during urgent care (C1P03, C1P04, C1P06). The third was *variation in staff readiness*. Multiple participants anticipated stronger uptake among younger staff and more resistance among older or less technologically confident staff (C1P03, C1P04, C1P07). In this respect, the stakeholder layer showed that support for the concept was broad but conditional on the technology being reliable, low-friction, and clearly assistive.

7.4.2 Institutional Layer

The institutional layer captures the organisational and work-system conditions that shape whether the concept could be practically integrated into care.

Workflows and Routines

Participants described HERO work as occurring in environments that were often noisy, crowded, and difficult to coordinate. Challenges included human error in triaging multiple alerts (C1P01), difficulty scribing during chaotic events (C1P02), missed post-code huddles (C1P03), unclear role allocation in busy rooms (C1P04, C1P10), and crowd control problems during responses (C1P05, C1P11).

> "Often times I found communication difficulty arises from so many people in the room and often people don't jump into allocating roles. If you're not streamlined to the role allocation, it becomes messy" (C1P10)

> "Sometimes the coordination of the code is the most complex part of it. And if the roles haven't been identified early... things can get messy. And there's too many people trying to achieve the same goal... it actually just gets harder" (C1P11)

These findings suggest that the equipment problem was inseparable from a broader workflow problem. This was also reflected in the kinds of enhancements participants proposed. Suggestions included AI-guided workflow prompts linked to clinical pathways such as sepsis or dysreflexia (C1P03), digital algorithms displayed on the trolley (C1P01, C1P11), voice-to-text documentation tools (C1P02), automated documentation templates (C1P10), and devices that could assist the team lead by presenting required tools at the right time (C1P07).

> "I can see that all of that can be automated, like conversations in a room, if it's recorded and then transcribed... that I guess frees up or we can have it frees up one person from being a scribe" (C1P02)

> "Maybe like... follow separate protocols. So, you know, if the robot or AI could go through the sepsis sort of pathway for our medical team to follow... to prompt, I guess, or remind or guide that sort of workflow" (C1P03)

These proposals indicate that participants were imagining a broader sociotechnical support system, not simply an automated cart.

Infrastructure and material conditions

The case also revealed substantial infrastructural issues. Participants described inconsistent or unreliable ward technologies, including broken thermometers (C1P03), non-working printers on COWs (C1P01, C1P04), touchscreens that wasted time (C1P03), and difficulty locating functioning observation machines or computers in unfamiliar wards (C1P06). Participants also reported practical problems associated with manual stock management, including cluttered trolleys (C1P02), time-consuming restocking (C1P02, C1P07), and the manual checking of expiry dates and AED batteries (C1P09).

> "We have broken thermometers all throughout the hospital... getting a working COW with a touchscreen and a working printer. Yeah, yes. Few and far between" (C1P03)

> "Every time we need to pull information about that patient... finding that information could be sometimes a problem... finding an OBS machine and stuff, so yeah, that sort of varies" (C1P06)

> "We normally get an external trolley [the orange duffel bag]... and that's when the chaos comes because not everybody knows that bank... you'll be like throwing everything here" (C1P04)

These are important findings because they show that any new robotic system would enter an environment where basic equipment reliability is already a recurring issue.

This has two implications. First, technologies that improve stock visibility, automated checking, and equipment location may address real pain points. Second, the success of any robotic trolley would depend not only on its own functionality, but also on whether it can be maintained within an infrastructure that already struggles to keep existing equipment fully operational.

Organisational capability and change readiness

Participants generally described UCH as adaptable and relatively open to innovation. Several referred to the hospital as supportive of change, with a younger workforce, a history of technological implementation, or a research-oriented culture (C1P02, C1P03, C1P05, C1P07, C1P11). This was reflected in comments such as "Innovation is part of CHS [Canberra Health System] values, so we're encouraged to be innovative" (C1P08).

> "It's a younger staff cohort as well, so they're used to change... I genuinely believe that most people would say yes, of course, that's one thing that I don't have to do, I don't have to run and get the trolley" (C1P11)

At the same time, participants also identified limits to this capacity, including staff turnover (C1P10), reliance on backend support and maintenance expertise (C1P05, C1P08), and the need for sufficient training to ensure safe adoption (C1P02, C1P06), with one participant noting that “it’d be better if there was more support and education” (C1P06).

This mixed picture is important from an institutional perspective. The setting appears receptive enough to trial innovation, but sustained implementation would still depend on structured onboarding, technical support, and organisational ownership of the system over time.

Built environment

Although the interviews focused more strongly on workflow and equipment than on physical layout, several comments pointed indirectly to built-environment issues. Participants described challenges associated with moving heavy or powered equipment such as hoists and slings (C1P02, C1P05), navigating different wards with variable familiarity (C1P06), and managing crowded clinical spaces during responses (C1P05, C1P10, C1P11). These findings suggest that spatial conditions would be highly relevant to any autonomous or semi-autonomous trolley design, particularly in relation to navigation accuracy, congestion, and safe operation alongside staff and patients.

This was also something I paid close attention to during my observations. One particularly important issue was that some HERO calls occurred outside ward environments. In these situations, staff used an alternative equipment setup — described in practice as the “orange duffel bag” — because the standard trolley could not be taken outside. This has important implications for automation. Any robotic design intended to support HERO mobilisation would need either to accommodate these off-ward responses or to define its operational scope clearly, rather than assuming that all activations occur in spaces accessible to a trolley-based system.

7.4.3 Ecosystem layer

The ecosystem layer highlights broader structural influences that shape whether the concept is acceptable and sustainable beyond immediate workflow needs.

One major issue was *regulation and accountability.* Participants raised concerns about medico-legal responsibility, privacy, and regulatory requirements for AI-enabled systems in clinical care (C1P08). Even where participants were optimistic about predictive systems or automated support, they stressed the need for human oversight and clear accountability structures (C1P08, C1P10).

> "There needs to be a medico-legal chain of responsibility for managing

> an outcome. And anything that says, well, we've delegated to a robot and the robot said it was fine, no one's going to accept that" (C1P08)

A second issue was *sustainability and resourcing.* Participants identified budget, long-term support, and staff expertise as practical barriers to implementation (C1P05, C1P06, C1P08). One senior medical participant noted that innovation may be valued in principle, but that maintaining systems over time is harder when expertise turns over or backend support is limited (C1P08).

> "The back-end support for any updates would have to be huge and continuing and ongoing, or it would just be another thing that you'd stop using because it's not updated for the last two years." (C1P08)

A third issue was *professional and cultural legitimacy.* Although most participants were positive about innovation, several anticipated resistance among older staff or those sceptical of AI (C1P01, C1P03, C1P04, C1P07). These comments suggest that broader cultural narratives around AI, rather than purely local workflow concerns, may influence implementation. At the same time, some participants described the hospital as unusually well placed to adopt emerging technologies because of its teaching and research orientation (C1P07, C1P11).

> "There will be lots of pushback. People will be cranky about having to learn a new system... but eventually when we do realise that this is effective and helpful... they'll be fine" (C1P07)

In this sense, the ecosystem layer revealed both enabling and constraining forces beyond the immediate ward setting.

7.5 Implications for HRC Design for RRS

Taken together, these findings show how the case study shifted the design concept from an initial *work-as-imagined* model toward a more grounded understanding of *work-as-done* (Hollnagel 2015). At the outset of the project, the concept was framed primarily as a robotic trolley intended to reduce the physical burden of equipment mobilisation during HERO calls. However, the interview, observation, and document data showed that HERO work in practice was more complex than this initial concept suggested.

For me as a designer, this case was therefore not only a way to analyse the setting, but also a way to revise the design problem itself. The data showed that equipment mobilisation was only one part of a broader system of work involving coordination, communication, documentation, stock checking, equipment maintenance, variable infrastructure, and differing spatial conditions across the hospital. This meant that the original trolley-centred concept did not fully reflect the realities of HERO work as performed in practice.

Applying STEER-H was especially useful in this respect. It supported a move away from viewing the design opportunity as a narrowly defined technical solution and toward understanding it as a sociotechnical design problem. This made it possible to see more clearly what would need to be accounted for in any revised proposal, and why future prototyping would need to proceed in a way that is responsive to the actual setting rather than driven only by the original idea.

A further implication of this case is that a meaningful design opportunity may not need to begin with robotics, or even with HRC, at all. Although the project was initially framed around a robotic trolley, the findings pointed to several more immediate and potentially lower-complexity intervention points. Many of the problems participants described concerned stock visibility, equipment tracking, workflow prompting, documentation support, maintenance monitoring, and access to reliable information at the point of care. These needs suggest that substantial value could be created through simpler sociotechnical interventions, such as digital stock-checking systems, automated expiry and battery alerts, equipment-location tracking, cognitive aids linked to clinical pathways, or documentation tools that reduce scribing burden during rapid response events. In this sense, the case did not simply refine a robotics concept; it also showed that the underlying design problem could be approached through a staged pathway.

7.6 Evaluating STEER-H through the case

The case suggests that the framework was valuable in three main ways.

First, it provided *descriptive coverage*. The data showed that the design opportunity involved much more than user acceptance of a robotic trolley. The framework made it possible to capture a wider set of influences, ranging from frontline concerns about stock checking and documentation to organisational issues such as equipment reliability and broader concerns about governance and sustainability.

Second, it provided *interpretive value*. The framework helped make sense of why the initial concept did not fully match work-as-done. What initially appeared to be a relatively bounded transport problem was shown, through the layered analysis, to be embedded in a wider network of workflow, infrastructure, and governance issues. This reframing would have been difficult to achieve through a purely acceptance-oriented lens.

Third, it provided *design value*. By distinguishing stakeholder, institutional, and ecosystem considerations while also allowing relationships between them to be traced, the framework helped identify what a more contextually appropriate system might look like.

At the same time, the case also highlighted a limitation of STEER-H. While the framework was effective in surfacing relevant sociotechnical factors and showing how they interacted, it was less explicit about how those factors should be prioritised or acted upon once identified.

It is also important to acknowledge that the research context limits how critically the framework can be evaluated here. Since the case study was oriented toward demonstrating, rather than subjecting it to a formal comparative test, the evaluation is necessarily partial.

7.7 Conclusion

This chapter presented a qualitative case study of the HERO team at UCH to demonstrate and evaluate the STEER-H framework in the context of a rapid response system. Beginning from an initial concept of a robotic trolley, the case used interview, observational, and documentary evidence to examine how equipment mobilisation and emergency support work are actually performed in practice. The case demonstrated how STEER-H helped reframe the problem from a narrowly defined trolley concept to a broader sociotechnical HRC opportunity shaped by stakeholder needs, institutional conditions, and ecosystem constraints.

Chapter 8

Case Study 2: Lokomat Rehabilitation

This chapter presents the second case study used to *demonstrate and evaluate* the STEER-H framework (Chapter 6) in a rehabilitation context. Whereas Case 1 examined a prospective HRC concept for rapid response work (Chapter 7), this case analyses an *established* rehabilitation robot — the Lokomat — as it is embedded in routine clinical practice. [1]

The Lokomat is a robotic gait training system designed to support repetitive, task-oriented walking therapy. In practice, it creates a tightly coupled form of physical human-robot interaction among patients, clinicians, and the device. Robotic systems such as the Lokomat® are increasingly used to support both patients and therapists. These systems exemplify physical human-robot interaction (pHRI) (De Santis et al. 2008) and can improve rehabilitation effectiveness through precise control, adaptability, and intensive personalised therapy (Park et al. 2024). Another key value proposition is the potential to reduce the labour-intensive demands of conventional gait rehabilitation, where therapists often provide substantial manual assistance (Moulaei et al. 2023).

While robotic rehabilitation technologies can be clinically effective, their integration into clinical settings is often constrained by technological, behavioural, organisational, and economic barriers (Turchetti et al. 2014). Their effective implementation also requires careful planning around staffing, patient flow, physical space, funding, and technical support (Lo et al. 2020). In addition, targeted training, collaboration with industry partners, and adaptive mindsets are important for successful integration (Chua and Kuah 2017). Reported barriers also include device malfunctions and adverse events, which highlight the importance of clinician training and pa-

[1] This case study was undertaken as part of a broader collaborative project with Elizabeth Williams, Damith Herath, Glenda Caldwell, and Grant Shaw; a resulting paper has been published (see Publications and Contribution Statement)

tient expectation management (Charette et al. 2023). Efficient training programs can support adoption (Judy et al. 2023), while therapist utilisation rates and stakeholder engagement remain critical to sustained use (Morrow et al. 2021). In light of these issues, this case is well suited to examining what “effective” robotics means in practice, not only in terms of patient outcomes, but also in terms of acceptability, integration, and sustainability. The case is therefore used to apply and evaluate the STEER-H framework retrospectively in a clinical environment.

8.1 Case Context

This case took place within the same organisational setting as Chapters 5 and 7, the University of Canberra Hospital.

The Lokomat had been introduced approximately six months before the study period. During the early roll-out phase, physiotherapists and physiotherapy assistants received training from the manufacturer. The rehabilitation gym in which the robot was installed primarily served inpatients and was equipped with a range of therapy tools and devices. The gym was typically staffed by 4.5 full-time equivalent (FTE) physiotherapists and allied health assistants, and around 30 patients accessed the space each day on average.

The robotic system used in this setting was the Lokomat (see Figure 8.1), developed by Hocoma. This robotic gait orthosis is designed to automate treadmill-based gait training for patients with conditions such as spinal cord injury or stroke. The system combines an adjustable leg exoskeleton, a dynamic body-weight support mechanism, and a treadmill, and may also include gamified virtual exercises intended to enhance motivation and engagement during therapy. First introduced more than two decades ago for use in rehabilitation practice and research (Jezernik et al. 2003), the Lokomat has since been installed in more than 1,000 sites worldwide, according to the manufacturer (Hocoma n.d.). Further details on the system's design and patient outcomes are provided in (Hocoma n.d.; Jezernik et al. 2003; Nam et al. 2017; Alashram et al. 2021; Baronchelli et al. 2021).

8.2 Overview of The Study

This case study involved eight participants: six from the physiotherapy team, including five physiotherapists and one physiotherapy assistant, and two involved in management, procurement, and the introduction of the Lokomat (Table 8.1).

Figure 8.1: Lokomat installed in the UCH rehabilitation gym.

Table 8.1.

Table 8.1: Participant groups and IDs for Case Study 2.

Role group	Participant IDs
Physiotherapy Team	C2P01, C2P02, C2P03, C2P04, C2P05, C2P06
Management and Governance	C2P07, C2P08

An interesting aspect of this case study was the contrast between participants' initial expectations of the Lokomat and their realised experiences following its implementation. In the sections that follow, I focus on this contrast and use STEER-H to examine how and why these differences emerged in practice.

8.2.1 Expectations versus Realised Experience

Participants initially described a strongly optimistic view of the Lokomat during early implementation. A central expectation was that the robot would increase therapy intensity and duration, particularly compared with conventional gait-harness sessions that were often shorter and constrained by therapist fatigue. One clinician explained that the team expected walking practice to expand from short blocks to much longer sessions:

> "... instead of someone getting a typical amount of walking practice [that] would be three times five minutes with the gait harness on a treadmill, we were hoping that would be extended to anything up to an hour." (C2P08)

In the same account, intensity was framed as a clinical priority linked to recovery thresholds: "intensity is what we were after." (C2P08)

Participants also anticipated that gamification features would improve engagement and sustain meaningful practice. The system's game-based interface was viewed as an advantage for motivation and repetition, reflected in statements such as:

> There are about 16 games that a patient can potentially play on the device, and we know that there's good evidence that gamified devices keep patients engaged with meaningful practice for longer. (C2P08)

A further expectation concerned therapist workload. Before Lokomat use, participants described manual gait facilitation as physically demanding and difficult to sustain over longer sessions. As one participant noted,

> If we wanted them to walk, we would have to pick up their affected limb and replicate what a gait would look like... it's also very fatiguing and tiring for the therapist. (C2P03)

.

Accordingly, several staff expected the robot to reduce the manual handling burden and therapist time-on-task. This expectation appeared explicitly in the data: "the common thought was that this would reduce the amount of therapist time on the device." (C2P08) and "a lot of our staff were excited for the rollout, expecting time to be saved and better patient outcomes." (C2P01)

In practice, after approximately six months of routine availability, participants reported that patient-centred expectations were largely realised, particularly in relation to motivation and willingness to engage in intensive walking practice.

However, operational expectations were less consistently met. Participants repeatedly described a gap between anticipated efficiency and day-to-day implementation demands: "we quickly learned that this device would not save our time. It would be the opposite. It would cost us more time." (C2P01) This misalignment was closely tied to staffing and workflow pressure, with participants noting that the robot was not labour-saving but labour-intensive: " it's not a labour-saving device... that comes at the cost of extra labour" (C2P01) and "to set up the machine it takes out two physios for an hour... from a staffing point of view and a timing point of view, it's been a challenge. (C2P04)".

These implementation pressures also affected utilisation. Participants described that the robot was expected to be used far more consistently than what was possible in practice. In several accounts, under-utilisation raised concern that the system could become a "white elephant" in routine service delivery: "it would have very much gone down the path of a white elephant... not being used because staff had to prioritise patient flow." (C2P08)

Participants also highlighted a knowledge-retention risk when utilisation dropped. One manager-level account described how loss of a single trained staff member led to prolonged non-use and erosion of local expertise:

> because we had someone who moved into another role, just the loss of one staff member meant that we couldn't use the device at all. So, for six weeks, the device hasn't been touched. (C2P08)

This was linked to concern about declining capability over time:

> we're starting to lose the knowledge base and the corporate knowledge in the particular area because the device is not being used every day. (C2P08)

To analyse the gap between what was expected and what was realised in practice, I use the STEER-H framework.

8.3 Demonstrating STEER-H Through the Case

8.3.1 Stakeholder Layer

At the stakeholder level, this case shows that the Lokomat was not simply either accepted or rejected. Rather, different stakeholder groups experienced different forms of value and burden. For patients, the robot was generally perceived as motivating, meaningful, and capable of enabling a kind of walking practice that was difficult to achieve through conventional therapy alone. Clinicians repeatedly linked this value to increased repetition, longer practice periods, and the motivational effect of immediate visual feedback and gamified exercises. As one participant explained:

> "Yeah, I think it's helped with their well-being and potentially with their mental health too… Each session they get high scores. They always want to beat the high score they did the time before so it's more motivating for them than just over ground or treadmill walking." (C2P03)

Similarly, participants described that families were often drawn into this motivational dynamic, with robot-generated statistics and game scores helping to sustain interest and encouragement across sessions. In this sense, the Lokomat appeared to align well with several stakeholder priorities at the patient and family level, particularly around engagement, intensity, and the emotional experience of therapy.

However, the stakeholder layer also reveals that acceptance was conditional and uneven. Clinicians were not opposed to the robot; indeed, many described excitement about its arrival and recognised its therapeutic promise. Yet their acceptance became qualified by the work required to operate it well, the need for advanced clinical reasoning, and the effort needed to manage patient expectations. One participant noted that patients could become unrealistically optimistic about what the robot would achieve:

> "I wouldn't say reluctant, but... one thing I've noticed is over-optimistic. They think that being on the robot will solve everything... 'I'm going to be walking out of the hospital after two sessions on the Lokomat'." (C2P05)

Clinician acceptance was also shaped by confidence and skill. Participants described that effective use depended not just on willingness to use technology, but on having the neurological knowledge and practical experience required to adjust parameters meaningfully. As one clinician put it, "It's good to already have a good foundation of neurological physiotherapy before you start on the robotics." (C2P06) Another stated that "the more influencing factor would be the operator's technological understanding, or their willingness to accept technology." (C2P05) Together, these accounts show that the stakeholder layer is not only about positive attitudes. It also concerns the conditions under which stakeholders perceive the technology as appropriate, manageable, and worthwhile in practice.

Several participants described harness discomfort, bruising, and the manual handling demands of set-up. Others noted that although the robot generated useful summary metrics, the data did not always provide the level of clinical specificity they wanted.

Viewed through STEER-H, the stakeholder layer therefore shows that the Lokomat generated substantial patient-facing value, but that this value was accompanied by unevenly distributed implementation burdens. Patients and families often experienced motivation and hope, while clinicians carried the responsibility of set-up, adjustment, safety, expectation management, and the integration of the robot into broader rehabilitation plans.

8.3.2 Institutional Layer

If the stakeholder layer shows why the Lokomat was valued, the institutional layer explains why that value was difficult to sustain in routine clinical practice. Across the interviews, the most persistent issues concerned workflow fit, staffing, training, procedures, and the reorganisation of work around the robot. In other words, the key problem was not whether the robot could provide benefit, but whether the organisation could absorb the demands associated with using it.

Workflows and routines emerged as a major source of friction. The robot did not replace existing therapy demands; rather, it was added on top of them. Participants repeatedly described that two staff members were required for safe setup and that sessions occupied a substantial block of time, thereby reducing the team's ability to deliver therapy elsewhere in the gym. One participant described this very directly:

> "We've had to introduce these robots without any additional staffing. And so, the robots don't replace usual therapy, they're in addition to usual therapy. So, we're still expected to do our previous workload, plus four therapist hours of robot therapy every day. So, it's a huge impact on our workload." (C2P02)

This mismatch between the robot and existing service routines was echoed across the data. Participants described having to change the structure of the gym, compress patient scheduling, and accept reduced therapy time for some non-Lokomat patients. As one clinician explained, "the robot takes an hour of your day gone just doing the robot and it takes two staff to do the robot" (C2P03), while another noted that "it's not just that we're missing out on one-on-one time with the patient, we're probably missing out on seeing three or four patients at that hour each" (C2P04). These accounts strongly suggest that the robot did not fit easily into the existing work system and, in practice, redistributed pressure across the wider rehabilitation service.

Training, governance, and organisational structure were also central institutional issues. Although initial training was provided, participants repeatedly described it as insufficient for confident and evidence-informed use. Importantly, the problem was not only learning how to operate the interface, but learning how to apply the robot clinically. One participant explained:

> "But there was no content that included research or evidence-based practice that helped us to apply the robot in terms of the dose. So, we didn't learn in the training how long the session should be with the person, how many times a week a person needs to be on the robot. We didn't learn anything about how much body weight support or guidance force we should be having." (C2P02)

This lack of guidance meant that local staff had to rely heavily on trial-and-error learning, internal peer support, and locally developed procedures. Participants described writing policies and safe operating procedures, creating emergency plans, and informally building competence over time through repeated practice. The absence of a dedicated robotics lead or stable staffing model further amplified the problem, as did concerns about knowledge retention when trained staff moved into other roles.

These findings show that the Lokomat was institutionally difficult to integrate, not because the organisation was resistant to innovation, but because the surrounding work system was not sufficiently configured to support routine, efficient, and sustainable use. This is precisely the kind of organisational misalignment that the institutional layer of STEER-H is intended to make visible.

8.3.3 Ecosystem layer

The ecosystem layer further explains why some of the difficulties seen in practice could not be understood solely as local operational problems. The Lokomat was introduced within a broader landscape of research ambitions, funding arrangements, professional expectations, and a still-maturing rehabilitation robotics field. These wider conditions shaped both the opportunities for adopting the robot and the limits of what the local team could realistically achieve.

At one level, the broader ecosystem clearly enabled the project. Participants described the Lokomat as part of a wider innovation agenda associated with the hospital's rehabilitation identity and its connection with the university. As one management participant stated:

> "...the initial motivation was really around research capacity building, using a novel technology such as neurorehabilitation to drive that research agenda in the hospital." (C2P07)

This broader ecosystem also included cultural aspirations. The project was described as a way of building an innovative workplace, attracting staff, and creating a progressive identity for the service. In that sense, the robot carried symbolic and strategic value beyond its immediate clinical use.

At the same time, the ecosystem layer also reveals why local implementation challenges persisted. A major issue was that capital investment in the robot was not matched by recurrent staffing support. Participants made clear that additional staffing had been sought but did not initially eventuate, even though such support was seen as necessary for full utilisation. As one management participant reflected:

> "We were aware of having limited resources and in actual fact we had requested more staff resources so that we could keep this to make sure that this device was fully utilised however that never eventuated." (C2P08)

The broader professional and industry field also shaped the case. Participants described robotic rehabilitation in Australia as still being in its "relative infancy" (C2P08), and clinicians spoke about the limited evidence available to guide dosing and parameter selection. This meant that some of the uncertainty experienced locally was not simply a failure of local planning, but reflected the immaturity of the wider evidence base and the limited availability of established models for practice. Likewise, participants described limited post-training support from the vendor and uncertainty about who, professionally, should be able to operate the robot over time. One manager had hoped that allied health assistants or other trained personnel might eventually supervise the system, but also expressed concern that professional ownership boundaries could restrict this possibility.

The ecosystem layer therefore shows that the Lokomat was embedded in a wider set of structural conditions that simultaneously enabled and constrained its use. University affiliation, research agendas, and innovation culture helped make adoption possible. However, weaknesses in recurrent funding, the limited maturity of the professional field, thin clinical guidance, and uncertain role boundaries undermined the sustainability of routine implementation. STEER-H is useful here because it draws attention to the fact that what appeared on the surface as a staffing or workflow problem was also, in part, a consequence of broader ecosystem conditions.

8.4 Interpreting the Lokomat's Difficulties in Practice

Overall, the three STEER-H layers suggest that the main issue in this case was not whether the Lokomat was a successful rehabilitation robot in general, but how that success was translated into a specific local work system. The robot had an established reputation, was already used in many rehabilitation settings, and was also seen locally as therapeutically valuable. Patients were often motivated by it, clinicians recognised its capacity to support intensive and repetitive gait practice, and the organisation viewed it as aligned with broader ambitions for innovation and research. Yet these strengths did not automatically produce smooth implementation. Instead, the case shows that even a well-established robot can be difficult to embed when local routines, staffing arrangements, training, and decision-making processes are not adequately configured around it.

From a sociotechnical design perspective, the difficulties observed here point to the need to redesign not only the technology-in-use, but also the surrounding work system (Cherns 1976, 1987). In this case, that may have meant creating staffing and scheduling arrangements that reflected the real demands of setup and supervision, allowing local teams to adapt procedures around patient flow rather than forcing use into existing routines, and ensuring that clinical knowledge, troubleshooting capacity, and operational decision-making sat close to the point where problems emerged. It may also have required training that extended beyond button-level operation to include dosing, parameter adjustment, and patient selection, alongside clearer mechanisms for sharing knowledge when experienced staff moved on. Seen in this way, the problem was not that the Lokomat failed, but that successful robotic rehabilitation depended on a better fit between the device, the people using it, and the organisational conditions required to sustain its use over time.

8.5 Evaluating STEER-H Through the Case

As in the RRS case, this chapter also provided an opportunity to examine the usefulness of STEER-H in practice. However, whereas the RRS case involved a prospective design situation, the Lokomat case tested the framework in a retrospective implementation context. In that sense, the value of STEER-H here was not simply that it could describe the case, but that it could help explain why a promising system remained difficult to embed in routine service delivery.

First, it provided *descriptive coverage*. The Lokomat case mapped clearly onto all three layers of the framework. The stakeholder layer captured how patients, clinicians, and managers experienced the robot differently. The institutional layer captured the organisational conditions shaping its use, including staffing, workflow, and training. The ecosystem layer captured broader influences such as funding, vendor support, and the emerging status of rehabilitation robotics. Taken together, these layers enabled a fuller description of the case than a purely clinical or user-centred account.

Second, it offered *interpretive value*. STEER-H helped make sense why a robot that was seen as beneficial and motivating in therapy was nevertheless difficult to sustain in routine practice. It showed that this was not due to a single issue, but to the interaction between stakeholder expectations, organisational constraints, and wider structural conditions.

Third, it had *evaluation value*. STEER-H made it possible to assess the Lokomat not only in terms of what it delivered for patients, but also in terms of whether it could be integrated and sustained in practice. From this perspective, the case suggests that the robot was clinically valuable, but operationally difficult to embed without stronger staffing support, better workflow fit, and more stable long-term support.

At the same time, the Lokomat case also highlighted a limitation of STEER-H that echoed the previous case. While the framework was effective in surfacing relevant sociotechnical factors and showing how they interacted, it was less explicit about how those factors should be prioritised or acted upon once identified. In this case, the framework clearly brought staffing, workflow fit, training, and longer-term organisational support into view, but it did not itself specify which of these issues should be addressed first or how implementation responses might best be sequenced in practice.

It is also important to acknowledge that the research context limits how critically the framework can be evaluated here. As in the RRS case, this chapter was oriented toward demonstrating and applying STEER-H rather than subjecting it to a formal analysis against alternative frameworks or methods. The evaluation is therefore necessarily partial.

8.6 Conclusion

This chapter evaluated STEER-H through the Lokomat case by showing how the framework could organise and interpret implementation issues across stakeholder, institutional, and ecosystem levels. In doing so, it demonstrated that STEER-H offers more than descriptive structure: it also helps make sense why a clinically promising robot may remain difficult to embed in routine practice.

The chapter therefore supports STEER-H as a useful framework for evaluating human-robot systems as sociotechnical arrangements. However, its broader value emerges more clearly when applied across contrasting contexts. The next chapter therefore brings this case together with the RRS study to develop cross-case insights and further assess the contribution of STEER-H.

Chapter 9

Discussion

Building on the preceding empirical chapters, the discussion moves from reporting individual study findings to interpreting what they collectively mean for healthcare HRC. It synthesises insights across the interviews, acceptance study, framework development, and case studies to show how the thesis contributes both explanatory understanding and practical guidance. In doing so, the chapter examines recurring patterns across the studies, relates these back to the research questions, and reflects on the broader implications and boundaries of the STEER-H framework.

9.1 Cross-Case Insights

Drawing on both case studies (Chapters 7 and 8), STEER-H proved useful in two very different contexts: a prospective design case centred on a rapid response support concept, and a retrospective implementation case centred on an established rehabilitation robot.

What worked well across both cases. A consistent strength of STEER-H was that it made visible issues that would have been easy to miss through a narrower acceptance- or technology-focused lens. In the RRS case, the framework helped shift the project from an initial idea of a robotic trolley toward a broader sociotechnical support system involving stock management, workflow prompting, documentation support, and equipment visibility. What first appeared to be a bounded transport problem was shown to be embedded in a larger network of coordination, infrastructure, and governance issues. In the Lokomat case, STEER-H similarly showed that positive clinical value and patient motivation did not automatically translate into smooth implementation. Instead, the robot's use depended on staffing, workflow fit, training, governance, and recurrent support. Taken together, these cases suggest that STEER-H worked well as a multilevel analytic lens because it helped connect local experiences of value and burden with the institutional and ecosystem conditions that shaped them.

Where the current framework was weaker. At the same time, the two cases also highlighted a limitation of the current version of STEER-H. While the framework was effective in surfacing relevant factors and showing how they interacted, it was less explicit about how those factors should be prioritised or acted upon once identified. This was especially visible in the Lokomat case, where the analysis clearly showed interacting problems of workflow, staffing, training, and recurrent support, but the framework itself did not specify which of these should be addressed first or how organisations should sequence responses over time. A similar issue appeared in the RRS case: STEER-H helped reframe the design problem very effectively, but it did not by itself provide a step-by-step method for moving from sociotechnical diagnosis to implementation planning. This limitation is consistent with the way STEER-H is defined in the thesis. Its current strength therefore lies in structuring reflection and diagnosis, while a weaker area remains the translation of those insights into prioritised implementation action.

9.2 Synthesis Against the Research Questions

In Chapter 1, I argued that the persistent gap between promising healthcare robotics prototypes and sustained real-world use is best understood as a sociotechnical problem. The studies reported in Chapters 4–8 provide complementary evidence for this claim, as they show how development pathways, acceptance conditions, and implementation constraints interact across multiple system levels. This section brings those strands together and explicitly maps them to the research questions, highlighting what the thesis now allows us to explain — and what it enables practitioners to do differently.

RQ1: How are HRC technologies developed and introduced into healthcare settings and how do these processes shape their use in healthcare settings?

RQ1 was addressed primarily through the exploratory semi-structured interviews reported in Chapter 4. Using reflexive thematic analysis, that chapter synthesised practitioner and expert accounts of designing, procuring, deploying, and using complex healthcare HRC. Across participants' varied roles, development and introduction were consistently described not as a linear technical rollout, but as a sociotechnical process shaped by interdependent actors, situated work practices, and wider system constraints.

That study showed that the development and introduction of healthcare HRC are not linear technical processes, but sociotechnical ones shaped by the interaction of three themes: an *interwoven stakeholder ecosystem*, *context-aware design and development*, and a *broader landscape* of regulatory, organisational, financial, and societal influences. Together, these themes show that how HRC technologies are developed and introduced directly shapes how they are taken up, adapted, and used in practice. More detailed discussion of how these themes answer the research question is provided in Chapter 6.

These dynamics were also evident in the case studies, which provide concrete examples of how development and introduction conditions shape downstream patterns of use. In the prospective Rapid Response System case (Chapter 7), the concept work made visible the breadth of the stakeholder ecosystem implicated by HRC in a healthcare setting: beyond intended users, the design space was immediately entangled with workflow requirements, responsibility allocation, and implementation feasibility considerations that sit outside the robot's core functionality. In the retrospective Lokomat case (Chapter 8), the same sociotechnical pattern appeared in routine practice. While patient-facing value could be clear, realised use was shaped by institutional capacity and the practical burdens of day-to-day operation—including staffing demands, scheduling and throughput constraints, and the need for training and knowledge retention to sustain capability over time. In other words, the way the technology was embedded organisationally became a primary determinant of utilisation and long-term integration.

RQ2: What factors influence the acceptance of HRC technologies in healthcare settings?

RQ2 was addressed primarily through the hospital-based quantitative acceptance study reported in Chapter 5. Building on technology acceptance literature, I argued that acceptance in healthcare cannot be treated as context-free: generic acceptance models risk overlooking the conditions that make clinical work distinctive. Accordingly, the study tested a context-specific acceptance model for the setting examined in this thesis, namely HRC in support of a hospital Rapid Response System.

The findings show that acceptance in this context extends beyond questions of whether the technology works or is easy to use, and is strongly shaped by constructs that reflect the accountability demands of acute care. In the RRS case study, acceptance was influenced by **trust**, **perceived risk**, and **ethical concerns**, alongside more familiar functional and workflow-related factors. This pattern supports the broader thesis claim that acceptance is not simply an individual attitude toward a technology, but a situated judgement about whether a system can be used responsibly within a safety-critical clinical environment.

Importantly, these findings suggest that RQ2 does not yield a single, fully generalizable set of acceptance factors applicable across all healthcare contexts. Rather, it points to the need for a context-sensitive approach to understanding acceptance, where relevant influences emerge in relation to the specific clinical setting, stakeholder roles, and organisational demands. For this reason, acceptance is positioned within the stakeholder layer of the STEER-H framework.

RQ3: How can insights from these sociotechnical processes be translated into practical guidance for the design and integration of HRC technologies in healthcare?

RQ3 was addressed through the translation of empirical and theoretical insights into the STEER-H framework (Chapter 6), and through its demonstration and refinement in the two case studies (Chapters 7-8). In line with the Design Science Research orientation of the thesis, the goal was to produce an artefact that can be used to structure design and integration work in real settings.

STEER-H operationalises the thesis findings by providing a layered set of determinants and decision points across the *stakeholder*, *institutional*, and *ecosystem* levels. This layered structure is the key translation mechanism: it turns sociotechnical complexity into an actionable way of asking "what needs to align, and where are the likely points of failure?" At the stakeholder layer, STEER-H foregrounds early and inclusive engagement across the interwoven stakeholder ecosystem identified in Chapter 4 and the acceptance determinants observed in Chapter 5. At the institutional layer, it directs attention to context-aware design for work-as-done, including workflow considerations, interoperability with existing systems, environmental fit, training capacity, and responsibility allocation. At the ecosystem layer, it makes explicit the broader landscape constraints that frequently shape feasibility and sustainment.

The case studies illustrate how this guidance can be helpful at different stages. In the RRS case, STEER-H supported early scoping by broadening the design brief and revealing dependencies that needed to be addressed before implementation. In the Lokomat case, it supported retrospective evaluation by showing that sustained use depended on organisational alignment, not clinical value alone. These applications suggest that STEER-H can help teams frame HRC challenges more realistically and identify where integration work is required. However, they also show that the framework currently supports diagnosis more strongly than prioritisation, indicating an important area for future refinement.

9.3 Positioning STEER-H

In Chapter 2, I established that STS-informed approaches provide mature ways to analyse how healthcare technologies become embedded in practice, including SEIPS (Carayon et al. 2006; Holden et al. 2013; Carayon et al. 2020), Sittig and Singh's eight-dimensional sociotechnical model (Sittig and Singh 2010), and NASSS (Greenhalgh et al. 2017). STEER-H is not intended to replace these approaches, but to complement them through a framework developed specifically for healthcare HRC, where the technology is embodied, interactive, and increasingly AI-enabled.

As argued in Section 2.5, comparatively few sociotechnical frameworks have been developed explicitly for robots in healthcare, despite their differences from many of the technologies that originally motivated healthcare STS frameworks, such as health information systems. Robots occupy physical space, operate in dynamic environments, interact in real time with patients and staff, and may exercise varying degrees of autonomy. They are also often introduced as relatively novel actors in care delivery, meaning that stakeholders bring pre-existing expectations about what "robots" mean in healthcare. These expectations can shape early acceptance, risk judgements, and perceptions of accountability, while also intensifying concerns about workflow disruption and coordination under joint action. General sociotechnical frameworks therefore remain highly valuable, but they do not always foreground the features that are especially salient for HRC.

Although STEER-H is HRC-specific, its structure was not created in isolation. It draws deliberately on key elements of established models and adapts them to the distinctive features of HRC, while incorporating empirical inputs from the literature synthesis, exploratory interviews, the acceptance study, and the case work. At the macro level, STEER-H's *ecosystem layer* is informed by NASSS, particularly its distinction between organisational conditions and the *wider system* in which technologies must be legitimated, funded, governed, and sustained (Greenhalgh et al. 2017). This influence is reflected in STEER-H's explicit attention to regulatory and governance arrangements, procurement and reimbursement logics, and broader public values and norms that shape what kinds of HRC are feasible and acceptable beyond a single site. STEER-H's *institutional layer* is informed by Carayon's work-system perspective as operationalised in SEIPS (Carayon et al. 2006; Holden et al.

2013; Carayon et al. 2020), carrying forward its focus on local workflow, resources, roles, and infrastructure. The *stakeholder layer*, in turn, emphasises work-as-done (Hollnagel 2015) and the situated judgements through which HRC are accepted, adapted, and used in practice.

A further distinguishing feature of STEER-H is its intended primary audience. The framework was developed principally for those involved in the design, development, and integration of healthcare HRC— especially developers, system designers, and implementation or integration teams. Although it can also be used by clinicians, managers, researchers, and evaluators, its primary purpose is to help those shaping the technology and its introduction think beyond device capability alone. It is intended to support earlier and more realistic consideration of the stakeholder, institutional, and ecosystem conditions that will influence whether an HRC system can be adopted, embedded, and sustained in practice. Framed this way, STEER-H is not only an analytic lens for explaining implementation challenges after the fact, but a practical tool for informing design and integration decisions.

The added value of STEER-H lies in increasing the practical specificity of sociotechnical analysis for HRC by making several determinants explicit and actionable.

Embodiment, built environment, and spatial workflow coupling. General frameworks such as SEIPS include the physical environment as a work-system element (Carayon et al. 2006; Holden et al. 2013), but HRC makes environmental fit a first-order design and integration constraint because robots occupy space, move (or must be constrained from moving), and interact in dense clinical settings. STEER-H therefore foregrounds spatial and environmental considerations as central to whether HRC can be used in routine practice.

Bridging measurement-level acceptance with system-level explanation. Acceptance models are useful for identifying how users perceive a technology, but those perceptions do not arise in isolation. They are shaped by the sociotechnical conditions of implementation, including workflow fit, training and support, accountability arrangements, and institutional legitimacy. STEER-H makes this relationship explicit by providing a structure that connects acceptance-related determinants — such as trust, perceived risk, and ethical concerns — to the institutional and ecosystem conditions that produce and shape them. In this way, acceptance is not treated as a purely individual preference, but as a situated judgement formed within a broader organisational and system context. This relationship is reflected in the acceptance study reported in Chapter 5, where constructs such as trust were closely tied to expectations about safe, accountable use in a clinical setting.

Chapter 10

Conclusion

This thesis set out to develop a situated understanding of how HRC systems are developed, introduced, and sustained in healthcare settings, and to translate that understanding into practical guidance for those involved in their design and integration. Across the thesis, I have argued that the persistent gap between promising robotic systems and their routine use in healthcare is best understood as a sociotechnical problem, shaped by the interactions of stakeholders, institutional conditions, and ecosystem factors.

To address this problem, I adopted a pragmatic mixed-methods approach within a Design Science Research framework. Through the literature review, exploratory expert interviews, hospital-based acceptance study, framework development, and two in situ case studies, I examined HRC from various perspectives. This enabled me to move from problem framing to empirical investigation, to the development and evaluation of a thesis artefact designed to support more effective healthcare robotics integration in practice.

The findings show that HRC in healthcare highlighted the importance of an interwoven stakeholder ecosystem, context-aware design, and the broader landscape of regulation, funding, governance, and professional norms. The acceptance study further showed that the intention to accept HRC is influenced not only by perceived usefulness and workflow fit but also by trust, perceived risk, and ethical concerns, particularly in safety-critical clinical settings. The two case studies reinforced these conclusions by showing how sociotechnical tensions arise differently across stages of adoption.

These strands of evidence support the central argument of this thesis: effective healthcare HRC depends on alignment across stakeholder, institutional, and ecosystem levels. On this basis, I developed STEER-H as a healthcare HRC-specific sociotechnical framework for making these cross-level dependencies visible and for helping to structure design and development, integration planning, and evaluation.

Rather than functioning as a prescriptive checklist, STEER-H provides a practical way of asking what needs to align, where likely points of failure may arise, and which challenges can be addressed through design choices versus broader organisational engagement.

10.1 Contribution to Knowledge

A healthcare HRC-specific sociotechnical framework (STEER-H). This thesis contributes STEER-H, a layered sociotechnical framework designed specifically for human-robot collaboration in healthcare. STEER-H extends established sociotechnical thinking by making HRC-relevant determinants explicit across stakeholder, institutional, and ecosystem layers — including collaboration boundaries, responsibility allocation, spatial workflow coupling, and sustainment conditions that arise when robots become embodied actors in clinical work. The framework is grounded in a synthesis of healthcare robotics literature and empirically derived insights from expert interviews and a hospital-based acceptance study, and it is demonstrated and refined through two contrasting case studies spanning prospective design and retrospective evaluation.

An empirically tested acceptance model for HRC in a Rapid Response System context. This thesis contributes an acceptance model tailored to HRC supporting a hospital Rapid Response System. The model demonstrates that acceptance in this setting is shaped not only by perceived usefulness and workflow fit, but also by trust, perceived risk, and ethical concerns — constructs that reflect the accountability demands and perceived stakes of acute care.

Actionable sociotechnical guidance for designing and integrating healthcare HRC. A further contribution is translational: the thesis shows how sociotechnical insights can be operationalised into practical guidance for HRC design and integration. Through STEER-H and its case-based evaluation, the thesis identifies recurring decision points and intervention targets — including early ecosystem and governance engagement, explicit specification of collaboration boundaries and accountability arrangements, design for spatial and workflow coupling, and sustainment planning for staffing, training, and knowledge retention. This contribution supports a shift from reactive troubleshooting during deployment toward earlier identification of misalignment and more targeted, system-level integration work.

In situ evidence across stages of adoption. This thesis contributes empirical evidence about healthcare HRC from two contrasting in situ case studies: a prospective evaluation of an HRC concept for rapid response work and a retrospective examination of the Lokomat in routine rehabilitation practice. Together, these cases illuminate how sociotechnical tensions play out differently across adoption stages, including how early governance and workflow coupling issues shape feasibility, and how staffing, scheduling, and knowledge-retention demands condition long-term utilisation even when patient-facing value is clear.

A mixed-methods Design Science approach for producing usable knowledge in healthcare HRC. Methodologically, the thesis demonstrates a pragmatic mixed-methods Design Science Research approach for healthcare HRC: exploratory expert interviews to surface sociotechnical determinants, a quantitative acceptance study to test context-relevant constructs, and case-study evaluation to demonstrate and refine the resulting framework. This provides a replicable pattern for generating both explanatory insight and design-relevant artefacts in safety-critical complex settings.

10.2 Contribution to Practice

STEER-H provides practitioners with a shared language and guiding structure for organising HRC development and integration work across the stakeholder, institutional, and ecosystem levels. For developers and integrators, the framework supports earlier identification of non-technical constraints that commonly surface late in projects and can derail deployments. By making these constraints visible, STEER-H enables more deliberate planning for sociotechnical alignment and longer-term sustainment.

Although STEER-H was developed primarily to support those designing and integrating HRC systems, it can also be used by other stakeholders involved in healthcare robotics adoption, including clinical leaders, operational managers, procurement teams, and governance and risk functions. In these settings, STEER-H is best treated as an adaptable scaffold: users may emphasise different elements of the framework depending on their role, the clinical domain, and the maturity of the technology. Used in this way, the framework can support cross-stakeholder coordination by providing a common set of sociotechnical considerations that can be localised to the specific implementation context.

10.3 Limitations

While this thesis makes several contributions, its findings should be interpreted in light of a number of limitations.

First, I necessarily balanced breadth and depth across the thesis. I set out to examine healthcare HRC as a sociotechnical phenomenon across multiple studies and contexts, which meant I could not explore every important concept — such as trust, workflow fit, perceived risk, and ethical concerns — in exhaustive depth. Instead, I focused on identifying how these factors shape HRC development, acceptance, and integration, and on translating those insights into a broader sociotechnical account and a practical framework. As a result, the thesis offers a cross-cutting understanding of how such factors matter in healthcare HRC, rather than a definitive treatment of any one construct in isolation.

Second, all empirical components of the thesis involved relatively small samples. This limits the breadth of representation and restricts the extent to which the findings can be generalised statistically. I addressed this, in part, through the overall research design, which combined multiple studies using different methods and perspectives. Rather than relying on a single dataset, I drew on converging evidence from expert interviews, a quantitative study, framework development, and two case studies. This does not remove the limitation, but it does strengthen the overall argument by showing recurring sociotechnical patterns across different forms of inquiry.

Third, while this thesis was not intended to focus specifically on the Australian healthcare context, most participants were based in Australia. As a result, the empirical material was shaped largely by the regulatory, organisational, funding, cultural, and professional conditions of that setting, and the findings may not transfer directly to other healthcare systems. At the same time, I sought to broaden the perspective captured in the exploratory work by including participants with international experience. This helped reduce the risk that the analysis would reflect only a narrow local view. Even so, the framework and findings should be understood as informed primarily by Australian-based perspectives and are therefore likely to require adaptation when applied in other national or institutional contexts.

Fourth, three of the four data collection activities in this research were conducted within a single site, UCH. This provided valuable contextual depth and allowed the research to examine recurring sociotechnical issues within a consistent organisational setting, but it also means that the findings were shaped to a significant extent by the particular conditions of that site. As a result, some of the barriers, enablers, and practical implications identified may reflect features specific to UCH rather than healthcare settings more broadly. Although the broader thesis design drew on multiple methods and perspectives, this concentration of data collection within one site remains a limitation and suggests the need for further work across a wider range of institutions.

Fifth, although STEER-H was developed to reflect issues that are especially salient in healthcare HRC, its development also required drawing on adjacent bodies of evidence where the HRC-specific literature remains limited. In particular, I drew on scholarship relating to robots in healthcare more broadly, as well as AI in healthcare, because these fields often provide more developed accounts of regulation, governance, and implementation constraints. This strengthens the framework by situating HRC within a wider sociotechnical and healthcare technology context, but it also means that some elements of STEER-H are informed by closely related domains rather than by a mature HRC-specific evidence base alone.

Sixth, it is important to clarify how the terms demonstration and evaluation are used in this thesis. Throughout the research, these terms are used in the Design Science Research sense: that is, to refer to the application, examination, and refinement of the thesis artefact in relation to empirical cases and real-world healthcare HRC scenarios. In this sense, STEER-H was demonstrated and evaluated by using it to structure analysis, make sociotechnical issues visible, and examine its explanatory and practical relevance across the case studies. However, this should be distinguished from a formal end-user evaluation study of the framework as an applied tool. Although STEER-H was developed through a Design Science Research process and was demonstrated and refined through the case studies, this thesis did not systematically evaluate the framework with its intended end-users. In particular, the research did not collect data on how developers, clinicians, implementation leads, procurement staff, or other healthcare stakeholders experience STEER-H when using it in practice. As a result, the thesis cannot make strong claims about the framework's usability, ease of application, or perceived utility across different user groups and project settings. The case studies provided an important opportunity to examine the explanatory and structuring value of STEER-H in relation to real-world healthcare HRC cases, but they were not designed as a formal evaluation of the framework's use by end-users. Further evaluation is therefore needed to understand how STEER-H is interpreted, used, adapted, and valued by different stakeholders involved in healthcare HRC design and integration.

10.4 Future Research

This thesis opens several directions for future research.

First, future research could apply and refine STEER-H across a wider range of healthcare contexts, robot types, and stages of adoption. In this thesis, the framework was developed and examined through studies spanning prospective concept development, acceptance modelling, and retrospective case evaluation. Further work is needed to test how well STEER-H travels across other clinical specialities, healthcare organisations, and forms of HRC, and to identify where additional tailoring may be required.

Second, future studies could build on the acceptance work by developing and testing context-specific models for other healthcare HRC applications. One of the key findings of this thesis is that acceptance is shaped by the particular demands of the clinical setting rather than by universal factors alone. This suggests value in examining how acceptance determinants vary across use cases, professional roles, patient groups, and care environments.

Third, there is a need for more longitudinal research on healthcare HRC. Much remains to be understood about how perceptions, patterns of use, and sociotechnical challenges evolve over time as systems move from early introduction to routine use, adaptation, and possible decline. Longitudinal work would be especially valuable for examining how acceptance stabilises or changes, how knowledge and capability are maintained, and how sustainment is shaped by organisational and ecosystem conditions.

Finally, future research could further explore how sociotechnical frameworks such as STEER-H can be translated into practical methods and tools for those involved in healthcare HRC projects, and how STEER-H can be formally evaluated as an applied framework for healthcare HRC design, integration, and evaluation. While this thesis focused on producing a usable framework for developers and integrators, and demonstrated and refined the framework through case-based analysis, further work is needed to examine how intended users engage with STEER-H in practice. There is scope to investigate how such guidance might be operationalised through workshops, assessment instruments, implementation planning tools, or evaluation templates that support cross-stakeholder coordination in practice. Such studies could involve developers, clinicians, implementation leads, procurement teams, governance stakeholders, and subject matter experts using STEER-H in workshops, design reviews, implementation planning sessions, usability sessions, or retrospective evaluations of existing robotic systems. Formal evaluation could examine usability, ease of application or interpretation, perceived utility, stakeholder alignment, and the extent to which STEER-H supports identification of sociotechnical risks and integration requirements.

10.5 Closing Statement

If this thesis leaves one central message, it is that the future of human-robot collaboration in healthcare will not be determined at the moment a robot proves it can work, but at the moment it proves it can belong. That should prompt a shift in perspective for developers and engineers. Healthcare HRC cannot be approached as a self-contained design problem, because the effects of these systems are never confined to the device itself. To design well in this space is therefore to adopt a sociotechnical systems view, one that recognises that technical decisions reverberate through workflows, professional roles, institutional arrangements, and ultimately the experience of care itself.

Epilogue

When I began this research, I was trying to make sense of an experience that unsettled my assumptions as an engineer. I had seen a rehabilitation robot progress from prototype to functional system, yet I had also seen how little that success guaranteed once it entered clinical work. This thesis has helped me understand that tension more clearly.

What I lacked at the time was a way to name the problem. This research has given me that language. Across this thesis, I have argued that human-robot collaboration in healthcare is a sociotechnical problem. That now feels less like an abstract claim and more like a clearer account of something I had already sensed in practice.

In the final months of this PhD, I joined a team supporting the uptake and use of technologies in rehabilitation hospitals in Queensland Health. I am still at the beginning of that work, with much to learn, but it has already sharpened the focus of this thesis for me. Working as part of a clinical team, and alongside physiotherapists and occupational therapists, has changed what I notice. Decisions about technology are shaped every day by staffing pressures, patient flow, documentation, competing priorities, time, and coordination.

From this vantage point, the barriers to uptake seem less dramatic and more ordinary. They appear in questions about who will use the device, who will train staff, where it will sit, when it can be scheduled, how risks are managed, and whether the benefits justify the work needed to sustain it. These are not secondary issues. They are part of what determines whether a technology can be used in practice.

This has reinforced for me that the future of healthcare robotics will depend on how well these systems fit within care settings, a message I have been trying to emphasise in this thesis. The STEER-H framework is one outcome of that effort. I do not see it as a final answer. I see it as a way of asking better questions earlier. I hope it helps engineers, researchers, and technology developers attend to the wider conditions that shape whether human-robot collaboration can work in practice.

Bibliography

Ait Ameur, M. A., Yang, E. and Brady, S. (2024), Advancing healthcare through intelligent human-robot collaboration: Overview, challenges and opportunities, IEEE, pp. 1–6.

Alaiad, A., Zhou, L. and Koru, G. (2013), 'An empirical study of home healthcare robots adoption using the UTUAT model'.

Alashram, A. R., Annino, G. and Padua, E. (2021), 'Robot-assisted gait training in individuals with spinal cord injury: A systematic review for the clinical effectiveness of Lokomat', *J Clin Neurosci* **91**, 260–269.

Alharbi, S. T. (2014), Trust and acceptance of cloud computing: A revised UTAUT model, IEEE, pp. 131–134.

Alla, S. (2024), An Integrated Theoretical Socio-Technical Framework for Implementing Service Robots' Integration in Healthcare, PhD thesis. `https://digitalcommons.odu.edu/emse_etds/241`

AlQudah, A. A., Al-Emran, M. and Shaalan, K. (2021), 'Technology acceptance in healthcare: A systematic review', *Appl. Sci. (Basel)* **11**(22), 10537.

Amarasingham, R., Plantinga, L., Diener-West, M., Gaskin, D. J. and Powe, N. R. (2009), 'Clinical information technologies and inpatient outcomes: a multiple hospital study: A multiple hospital study', *Arch. Intern. Med.* **169**(2), 108–114.

Ammenwerth, E. (2019), 'Technology acceptance models in health informatics: TAM and UTAUT', *Stud. Health Technol. Inform.* **263**, 64–71.

Andriella, A., Torras, C. and Alenyà, G. (2025), *Personalising Human-Robot Interactions in Social Contexts*, Vol. 159 of *Springer Tracts in Advanced Robotics*, Springer Nature Switzerland, Cham. `https://link.springer.com/10.1007/978-3-031-71732-1`

Arents, J., Abolins, V., Judvaitis, J., Vismanis, O., Oraby, A. and Ozols, K. (2021), 'Human–robot collaboration trends and safety aspects: A systematic review', *J. Sens. Actuator Netw.* **10**(3), 48.

Bader, K. B., Hendley, S. A. and Bollen, V. (2021), 'Assessment of collaborative robot (cobot)-assisted histotripsy for venous clot ablation', *IEEE Trans. Biomed. Eng.* **68**(4), 1220–1228.

Bakshi, G., Kumar, A. and Puranik, A. N. (2022), Adoption of robotics technology in healthcare sector, *in* S. Dhar, S. C. Mukhopadhyay, S. N. Sur and C.-M. Liu, eds, 'Advances in Communication, Devices and Networking', Lecture notes in electrical engineering, Springer Singapore, Singapore, pp. 405–414. `http://dx.doi.org/10.1007/978-981-16-2911-2_42`

Baronchelli, F., Zucchella, C., Serrao, M., Intiso, D. and Bartolo, M. (2021), 'The Effect of Robotic Assisted Gait Training With Lokomat® on Balance Control After Stroke: Systematic Review and Meta-Analysis', *Front Neurol* **12**, 661815.

Bauer, A., Wollherr, D. and Buss, M. (2008), 'Human–robot collaboration: A survey', *Int. J. HR* **05**(01), 47–66.

Baumkircher, A., Seme, K., Munih, M. and Mihelj, M. (2022), 'Collaborative robot precision task in medical microbiology laboratory', *Sensors (Basel)* **22**(8), 2862.

Baxter, G. and Sommerville, I. (2011), 'Socio-technical systems: From design methods to systems engineering', *Interacting with Computers* **23**(1), 4–17.

Beuscher, L. M., Fan, J., Sarkar, N., Dietrich, M. S., Newhouse, P. A., Miller, K. F. and Mion, L. C. (2017), 'Socially assistive robots: Measuring older adults' perceptions', *J. Gerontol. Nurs.* **43**(12), 35–43.

Blandford, A. (2019), 'HCI for health and wellbeing: Challenges and opportunities', *Int. J. Hum. Comput. Stud.* **131**, 41–51. `http://dx.doi.org/10.1016/j.ijhcs.2019.06.007`

Blijleven, V., Hoxha, F. and Jaspers, M. (2022), 'Workarounds in Electronic Health Record Systems and the Revised Sociotechnical Electronic Health Record Workaround Analysis Framework: Scoping Review', *Journal of Medical Internet Research* **24**(3), e33046.

Bonet Olivencia, S. and Sasangohar, F. (2023), 'A sociotechnical framework for integration of telehealth into clinical workflow', *IISE Transactions on Healthcare Systems Engineering* **13**(3), 248–259. _eprint: https://doi.org/10.1080/24725579.2023.2211083. `https://doi.org/10.1080/24725579.2023.2211083`

Bowyer, S. A. and Rodriguez Y Baena, F. (2014), 'Deformation invariant bound-

ing spheres for dynamic active constraints in surgery', *Proc. Inst. Mech. Eng. H* **228**(4), 350–361.
http://dx.doi.org/10.1177/0954411914527440

Brahmi, B., El Bojairami, I., Laraki, M.-H., El-Bayeh, C. Z. and Saad, M. (2021), 'Impedance learning control for physical human-robot cooperative interaction', *Math. Comput. Simul.* **190**, 1224–1242.
http://dx.doi.org/10.1016/j.matcom.2021.07.016

Brahmi, B., Laraki, M. H., Saad, M., Rahman, M. H., Ochoa-Luna, C. and Brahmi, A. (2019), 'Compliant adaptive control of human upper-limb exoskeleton robot with unknown dynamics based on a Modified Function Approximation Technique (MFAT)', *Rob. Auton. Syst.* **117**, 92–102.
http://dx.doi.org/10.1016/j.robot.2019.02.017

Braithwaite, J., Churruca, K., Ellis, L. A., Long, J. c., Clay-Williams, R., Damen, N., Herkes, J., Pomare, C. and Ludlow, K. (2017), *Complexity science in healthcare - aspirations, approaches, applications and accomplishments: a white paper*, Macquarie University, Macmillan Education Australia, Macquarie University, N.S.W., South Yarra. OCLC: 1001721355.

Braun, V. and Clarke, V. (2012), Thematic analysis, *in* 'APA handbook of research methods in psychology, Vol 2: Research designs: Quantitative, qualitative, neuropsychological, and biological', APA handbooks in psychology®, American Psychological Association, Washington, DC, US, pp. 57–71.

Breimaier, H. E., Heckemann, B., Halfens, R. J. G. and Lohrmann, C. (2015), 'The Consolidated Framework for Implementation Research (CFIR): a useful theoretical framework for guiding and evaluating a guideline implementation process in a hospital-based nursing practice', *BMC Nursing* **14**(1), 43.
https://doi.org/10.1186/s12912-015-0088-4

Brugha, R. and Varvasovszky, Z. (2000), 'Stakeholder analysis: a review', *Health Policy and Planning* **15**(3), 239–246.

Bryman, A. (2006), 'Integrating quantitative and qualitative research: How is it done?', *Qualitative Research* **6**(1), 97–113.

Brünett, M., Gebert, A. and Weidner, F. (2025), 'Exploring healthcare staff's attitudes and perceptions of robot use in nursing care in Germany', *Int. J. Soc. Robot.* pp. 1–12.
http://dx.doi.org/10.1007/s12369-025-01275-w

Buntin, M. B., Burke, M. F., Hoaglin, M. C. and Blumenthal, D. (2011), 'The benefits of health information technology: a review of the recent literature shows predominantly positive results', *Health Aff. (Millwood)* **30**(3), 464–471.
http://dx.doi.org/10.1377/hlthaff.2011.0178

Burden, A. G., Caldwell, G. A. and Guertler, M. R. (2022), 'Towards human–robot collaboration in construction: current cobot trends and forecasts', *Constr. Robot.* **6**(3), 209–220.
https://link.springer.com/article/10.1007/s41693-022-00085-0

Busby Grant, J. and Herath, D. (2022), Social robots: Principles of interaction design and user studies, *in* D. Herath and D. St-Onge, eds, 'Foundations of Robotics', Springer Nature Singapore, Singapore, pp. 377–413.
https://doi.org/10.1007/978-981-19-1983-1_13

Buxbaum, H., Sen, S. and Kremer, L. (2019), 'An investigation into the implication of human-robot collaboration in the health care sector', *IFAC-PapersOnLine* **52**(19), 217–222.
http://dx.doi.org/10.1016/j.ifacol.2019.12.100

Campanella, P., Lovato, E., Marone, C., Fallacara, L., Mancuso, A., Ricciardi, W. and Specchia, M. L. (2016), 'The impact of electronic health records on healthcare quality: a systematic review and meta-analysis', *Eur. J. Public Health* **26**(1), 60–64.
https://academic.oup.com/eurpub/article-pdf/26/1/60/7472041/ckv122.pdf

Carayon, P. (2006), 'Human factors of complex sociotechnical systems', *Appl. Ergon.* **37**(4), 525–535.
http://dx.doi.org/10.1016/j.apergo.2006.04.011

Carayon, P., Bass, E., Bellandi, T., Gurses, A., Hallbeck, S. and Mollo, V. (2011), 'Socio-technical systems analysis in health care: A research agenda', *IIE Trans. Healthc. Syst. Eng.* **1**(1), 145–160.
https://pmc.ncbi.nlm.nih.gov/articles/PMC3351758/

Carayon, P., Hundt, A. S., Karsh, B., Gurses, A. P., Alvarado, C. J., Smith, M. and Brennan, P. F. (2006), 'Work system design for patient safety: the SEIPS model', *Quality & Safety in Health Care* **15**(Suppl 1), i50–i58.
https://pmc.ncbi.nlm.nih.gov/articles/PMC2464868/

Carayon, P., Wooldridge, A., Hoonakker, P., Hundt, A. S. and Kelly, M. M. (2020),

'SEIPS 3.0: Human-centered design of the patient journey for patient safety', *Applied Ergonomics* **84**, 103033.
https://linkinghub.elsevier.com/retrieve/pii/S000368701930239X

Catchpole, K., Cohen, T., Alfred, M., Lawton, S., Kanji, F., Shouhed, D., Nemeth, L. and Anger, J. (2024), 'Human factors integration in robotic surgery', *Hum. Factors* **66**(3), 683–700.
https://doi.org/10.1177/00187208211068946

Charette, C., Déry, J., Blanchette, A. K., Faure, C., Routhier, F., Bouyer, L. J. and Lamontagne, M.-E. (2023), 'A systematic review of the determinants of implementation of a locomotor training program using a powered exoskeleton for individuals with a spinal cord injury', *Clin Rehabil* **37**(8), 1119–1138.

Chen, K., Lou, V. W. and Cheng, C. Y. M. (2023), 'Intention to use robotic exoskeletons by older people: A fuzzy-set qualitative comparative analysis approach', *Comput. Human Behav.* **141**(107610), 107610.
http://dx.doi.org/10.1016/j.chb.2022.107610

Chen, N. (2018), Acceptance of social robots by aging users: Towards a pleasure-oriented view, *in* P.-L. P. Rau, ed., 'Lecture Notes in Computer Science', 10911 edn, Lecture notes in computer science, Springer International Publishing, Cham, pp. 387–397.
https://link.springer.com/10.1007/978-3-319-92141-9_30

Cherns, A. (1976), 'The Principles of Sociotechnical Design', *Human Relations* **29**(8), 783–792.
https://journals.sagepub.com/doi/10.1177/001872677602900806

Cherns, A. (1987), 'Principles of Sociotechnical Design Revisted', *Human Relations* **40**(3), 153–161.
https://doi.org/10.1177/001872678704000303

Cherryholmes, C. H. (1992), 'Notes on Pragmatism and Scientific Realism', *Educational Researcher* . Publisher: Sage PublicationsSage CA: Thousand Oaks, CA.
http://dx.doi.org/10.3102/0013189X021006013

Chiriatti, G., Bottiglione, A. and Palmieri, G. (2022), 'Manipulability optimization of a rehabilitative collaborative robotic system', *Machines* **10**(6), 452.
http://dx.doi.org/10.3390/machines10060452

Chua, K. S. G. and Kuah, C. W. K. (2017), 'Innovating With Rehabilitation Technology in the Real World: Promises, Potentials, and Perspectives', *Am J Phys Med Rehabil* **96**(10 Suppl 1), S150–S156.

Clegg, C. W. (2000), 'Sociotechnical principles for system design', *Applied Ergonomics* **31**(5), 463–477.
https://www.sciencedirect.com/science/article/pii/S0003687000000090

Cocosila, M., Archer, N. and Yuan, Y. (2009), 'Early investigation of new information technology acceptance: A perceived risk - motivation model', *Commun. Assoc. Inf. Syst.* **25**.
https://aisel.aisnet.org/cais/vol25/iss1/30

Coiera, E., Ash, J. and Berg, M. (2016), 'The unintended consequences of health information technology revisited', *Yearb. Med. Inform.* (1), 163–169.
http://dx.doi.org/10.15265/IY-2016-014

Colgate, J. E., Wannasuphoprasit, W. and Peshkin, M. A. (1996), Cobots: Robots for Collaboration With Human Operators.

Colucci, G., Tagliavini, L., Carbonari, L., Cavallone, P., Botta, A. and Quaglia, G. (2021), 'Paquitop.Arm, a mobile manipulator for assessing emerging challenges in the COVID-19 pandemic scenario', *Robotics* **10**(3), 102.
http://dx.doi.org/10.3390/robotics10030102

Conti, D., Cattani, A., Di Nuovo, S. and Di Nuovo, A. (2015), A cross-cultural study of acceptance and use of robotics by future psychology practitioners, IEEE, pp. 555–560.

Cresswell, K., Cunningham-Burley, S. and Sheikh, A. (2018), *Health care robotics: Qualitative exploration of key challenges and future directions*, Vol. 20.
https://www.jmir.org/2018/7/e10410

Creswell, J. W. and Creswell, J. D. (2017), 'Research design: Qualitative, quantitative, and mixed methods approaches'.

Dahlberg, T., Mallat, N. and Öörni, A. (2003), 'Trust enhanced technology acceptance model - consumer acceptance of mobile payment solutions'.

Darwish, S., EL Berry, K., Elfiky, E., Ali, W. and Abd El Mageed, H. (2023), 'Artificial intelligence robotics utilization in relation to wellbeing, burnout and stress among operating room nurses', *Menoufia Nursing Journal* **8**(3), 107–121.
https://menj.journals.ekb.eg/article_324863.html

David, D., Thérouanne, P. and Milhabet, I. (2022), 'The acceptability of social

robots: A scoping review of the recent literature', *Comput. Human Behav.* **137**(107419), 107419.
http://dx.doi.org/10.1016/j.chb.2022.107419

Davis, F. D. (1989), 'Perceived usefulness, perceived ease of use, and user acceptance of information technology', *MIS Q.* **13**, 319–340.

Davis, M. C., Challenger, R., Jayewardene, D. N. W. and Clegg, C. W. (2014), 'Advancing socio-technical systems thinking: A call for bravery', *Applied Ergonomics* **45**(2, Part A), 171–180.
https://www.sciencedirect.com/science/article/pii/S000368701300032X

de Graaf, M. M. A. (2016), 'An ethical evaluation of human–robot relationships', *Int. J. Soc. Robot.* **8**(4), 589–598.
https://doi.org/10.1007/s12369-016-0368-5

De Santis, A., Siciliano, B., De Luca, A. and Bicchi, A. (2008), 'An atlas of physical human–robot interaction', *Mechanism and Machine Theory* **43**(3), 253–270.
https://www.sciencedirect.com/science/article/pii/S0094114X07000547

Deloitte (2021), 'Socio-economic impact of AI on European health systems | Deloitte Belgium'.
https://www.deloitte.com/be/en/Industries/health-care/research/the-socio-economic-impact-of-ai-on-healthcare.html

Deloitte (2025), '2025 global health care outlook'.
https://www.deloitte.com/us/en/insights/industry/health-care/life-sciences-and-health-care-industry-outlooks/2025-global-health-care-executive-outlook.html

Denecke, K. and Baudoin, C. R. (2022), 'A review of artificial intelligence and robotics in transformed health ecosystems', *Front. Med. (Lausanne)* **9**, 795957.
http://dx.doi.org/10.3389/fmed.2022.795957

Deniz, C. and Gökmen, G. (2021), 'A new robotic application for COVID-19 specimen collection process', *Journal of Robotics and Control* **3**(1), 73–77.
http://dx.doi.org/10.18196/jrc.v3i1.11659

Densford, F. (2016), 'FDA: TransEnterix Surgibot 510(k) does not meet criteria for "substantial equivalence", shares plummet'.
https://www.massdevice.com/fda-transenterix-not-meet-criteria-substantial-equival

Department of Industry Science and Resources (2024), 'National Robotics Strategy'.
https://www.industry.gov.au/publications/national-robotics-strategy

Di Nucci, E., Thybo Jensen, R. and Tupasela, A. (2019), Ethics of Medical AI: The Case of Watson for Oncology. Publication Title: Social Science Research Network.
https://papers.ssrn.com/abstract=3432317

Dionisio, V. C. and Brown, D. A. (2016), 'Collaborative robotic biomechanical interactions and gait adjustments in young, non-impaired individuals', *J. Neuroeng. Rehabil.* **13**(1), 57.
http://dx.doi.org/10.1186/S12984-016-0166-1

Dwyer, S. C. and Buckle, J. L. (2009), 'The Space Between: On Being an Insider-Outsider in Qualitative Research', *International Journal of Qualitative Methods* **8**(1), 54–63.
https://doi.org/10.1177/160940690900800105

Elendu, C., Amaechi, D. C., Elendu, T. C., Jingwa, K. A., Okoye, O. K., John Okah, M., Ladele, J. A., Farah, A. H. and Alimi, H. A. (2023), 'Ethical implications of AI and robotics in healthcare: A review', *Medicine (Baltimore)* **102**(50), e36671.
http://dx.doi.org/10.1097/MD.0000000000036671

Engelbart, D. C. (1962), 'Augmenting human intellect: a conceptual framework'.

England, K. V. L. (1994), 'Getting Personal: Reflexivity, Positionality, and Feminist Research', *The Professional Geographer* **46**(1), 80–89.

Erdogan, K., Acun, O., Kucukmanisa, A., Duvar, R., Bayramoglu, A. and Urhan, O. (2020), 'KEBOT: An artificial intelligence based comprehensive analysis system for FUE based hair transplantation', *IEEE Access* **8**, 200461–200476.
http://dx.doi.org/10.1109/ACCESS.2020.3035637

Faheem, H. and Dutta, S. (2023), 'Artificial intelligence failure at IBM 'Watson for oncology'', *ICFAI J. Knowl. Manag.* **21**(3), 47–75.

Fernandes, B. E., Holroyd-Leduc, J. M., Eng, J. Z., Charbonneau, M., Lashewicz, B. M. and Toohey, A. M. (2025), 'Implementing robotic pets in continuing care settings: A scoping review of barriers and facilitators', *J. Am. Geriatr. Soc.* .
http://dx.doi.org/10.1111/jgs.19510

Fontúrbel, C., Cisnal, A., Fraile-Marinero, J. C. and Pérez-Turiel, J. (2023), 'Force-based control strategy for a collaborative robotic camera holder in laparoscopic

surgery using pivoting motion', *Front. Robot. AI* **10**, 1145265.
`http://dx.doi.org/10.3389/FROBT.2023.1145265`

Freeman, W. D., Sanghavi, D. K., Sarab, M. S., Kindred, M. S., Dieck, E. M., Brown, S. M., Szambelan, T., Doty, J., Ball, B., Felix, H. M., Dove, J. C., Mallea, J. M., Soares, C. and Simon, L. V. (2021), 'Robotics in simulated COVID-19 patient room for health care worker effector tasks: Preliminary, feasibility experiments', *Mayo Clin. Proc. Innov. Qual. Outcomes* **5**(1), 161–170.
`http://dx.doi.org/10.1016/J.MAYOCPIQO.2020.12.005`

Gagnon, M.-P., Desmartis, M., Labrecque, M., Car, J., Pagliari, C., Pluye, P., Frémont, P., Gagnon, J., Tremblay, N. and Légaré, F. (2012), 'Systematic review of factors influencing the adoption of information and communication technologies by healthcare professionals', *Journal of Medical Systems* **36**(1), 241–277.

Galluppi, F., Urdiales, C., Sanchez-Tato, I., Sandoval, F. and Belardinelli, M. O. (2009), 'A study on a shared control navigation system: human/robot collaboration for assisting people in mobility', *Cogn. Process.* **10 Suppl 2**(S2), S215–8.
`http://dx.doi.org/10.1007/s10339-009-0274-y`

Gaudiello, I., Zibetti, E., Lefort, S., Chetouani, M. and Ivaldi, S. (2016), 'Trust as indicator of robot functional and social acceptance. An experimental study on user conformation to iCub answers', *Comput. Human Behav.* **61**(1), 633–655.
`http://dx.doi.org/10.1016/j.chb.2016.03.057`

Gervasi, R., Mastrogiacomo, L. and Franceschini, F. (2020), 'A conceptual framework to evaluate human-robot collaboration', *The International Journal of Advanced Manufacturing Technology* **108**(3), 841–865.
`https://doi.org/10.1007/s00170-020-05363-1`

Greenhalgh, T. (2019), 'Why health technology projects so often fail'.
`https://insightplus.mja.com.au/2019/15/why-health-technology-projects-so-often-fa`

Greenhalgh, T., Wherton, J., Papoutsi, C., Lynch, J., Hughes, G., A'Court, C., Hinder, S., Fahy, N., Procter, R. and Shaw, S. (2017), 'Beyond adoption: A new framework for theorizing and evaluating nonadoption, abandonment, and challenges to the scale-up, spread, and sustainability of health and care technologies', *J. Med. Internet Res.* **19**(11), e367.

Guemghar, I., Pires de Oliveira Padilha, P., Abdel-Baki, A., Jutras-Aswad, D., Paquette, J. and Pomey, M.-P. (2022), 'Social robot interventions in mental health care and their outcomes, barriers, and facilitators: Scoping review', *JMIR Ment.*

Health **9**(4), e36094.
http://dx.doi.org/10.2196/36094

Guertler, M., Tomidei, L., Sick, N., Carmichael, M., Paul, G., Wambsganss, A., Hernandez Moreno, V. and Hussain, S. (2023), 'When is a robot a cobot? Moving beyond manufacturing and arm-based cobot manipulators', *Proc. Des. Soc.* **3**, 3889–3898.

Gumus, E. and Alan, H. (2025), 'Perspectives of physicians, nurses, and patients on the use of artificial intelligence and robotic nurses in healthcare', *Int. Nurs. Rev.* **72**(2), e70017.
http://dx.doi.org/10.1111/inr.70017

Gutman, D., Olatunji, S. A., Markfeld, N., Givati, S., Sarne-Fleischmann, V., Oron-Gilad, T. and Edan, Y. (2023), 'Evaluating levels of automation with different feedback modes in an assistive robotic table clearing task for eldercare', *Appl. Ergon.* **106**(103859), 103859.
http://dx.doi.org/10.1016/j.apergo.2022.103859

Gómez-González, E. (2020), *Artificial Intelligence in Medicine and Healthcare: applications, availability and societal impact.*
https://publications.jrc.ec.europa.eu/repository/handle/JRC120214

Haidegger, T., Kovács, L., Precup, R.-E., Benyó, B., Benyó, Z. and Preitl, S. (2012), 'Simulation and control for telerobots in space medicine', *Acta Astronaut.* **81**(1), 390–402.
http://dx.doi.org/10.1016/j.actaastro.2012.06.010

Hair, J. F. J., Hult, G. T. M., Ringle, C. M. and Sarstedt, M. (2022), 'A primer on partial least squares structural equation modeling (PLS-SEM)(Third Edit)', *SAGE Publications Inc* .

Hanafiah, M. (2020), 'Formative vs. Reflective measurement model: Guidelines for structural equation modeling research', *International Journal of Analysis and Applications* **18**(5), 876–889.

Hazarika, I. (2020), 'Artificial intelligence: opportunities and implications for the health workforce', *Int. Health* **12**(4), 241–245.

Hentout, A., Aouache, M., Maoudj, A. and Akli, I. (2019), 'Human–robot interaction in industrial collaborative robotics: a literature review of the decade 2008–2017', *Adv. Robot.* **33**(15-16), 764–799.
https://www.tandfonline.com/doi/abs/10.1080/01691864.2019.1636714

Herath, D. C., Martin, L., Doolan, S. and Grant, J. B. (2023), Robots and aged care: A case study assessing implementation of service robots in an aged care home, IEEE, pp. 1641–1647.

Hevner, A. R. (2007), 'A three cycle view of design science research', *Scandinavian journal of information systems* **19**(2), 4.

Hevner, A. R., March, S. T., Park, J. and Ram, S. (2004), 'Design science in information systems research', *MIS quarterly* pp. 75–105.
https://www.jstor.org/stable/25148625

Hocoma (n.d.), 'About Us'. Publication Title: About us.
https://www.hocoma.com/hocoma/about-us-2/

Hogan, J., Grant, G., Kelly, F. and O'Hare, J. (2020), 'Factors influencing acceptance of robotics in hospital pharmacy: a longitudinal study using the Extended Technology Acceptance Model', *Int. J. Pharm. Pract.* **28**(5), 483–490.
https://doi.org/10.1111/ijpp.12637

Holden, R. J., Carayon, P., Gurses, A. P., Hoonakker, P., Hundt, A. S., Ozok, A. A. and Rivera-Rodriguez, A. J. (2013), 'SEIPS 2.0: a human factors framework for studying and improving the work of healthcare professionals and patients', *Ergonomics* **56**(11), 1669–1686.

Holden, R. J. and Karsh, B.-T. (2010), 'The technology acceptance model: its past and its future in health care', *J. Biomed. Inform.* **43**(1), 159–172.
https://www.sciencedirect.com/science/article/pii/S1532046409000963

Hollnagel, E. (2015), Why is Work-as-Imagined Different from Work-as- Done?, *in* 'Resilient Health Care, Volume 2', CRC Press. Num Pages: 16.

Hollnagel, E. and Woods, D. D. (2005), *Joint cognitive systems: Foundations of cognitive systems engineering*, CRC press.
https://api.taylorfrancis.com/content/books/mono/download?identifierName=doi&identifierValue=10.1201/9781420038194&type=googlepdf

Holtrop, J. S., Estabrooks, P. A., Gaglio, B., Harden, S. M., Kessler, R. S., King, D. K., Kwan, B. M., Ory, M. G., Rabin, B. A., Shelton, R. C. and Glasgow, R. E. (2021), 'Understanding and applying the RE-AIM framework: Clarifications and resources', *Journal of Clinical and Translational Science* **5**(1), e126.

Hsieh, P.-J. (2015), 'Physicians' acceptance of electronic medical records exchange:

an extension of the decomposed TPB model with institutional trust and perceived risk', *Int. J. Med. Inform.* **84**(1), 1–14.
https://www.sciencedirect.com/science/article/pii/S1386505614001622

Hu, Z. J., Wang, Z., Huang, Y., Sena, A., Rodriguez y Baena, F. and Burdet, E. (2023), 'Towards human-robot collaborative surgery: Trajectory and strategy learning in bimanual peg transfer', *IEEE Robot. Autom. Lett.* **8**(8), 4553–4560.
http://dx.doi.org/10.1109/LRA.2023.3285478

Hung, L., Liu, C., Woldum, E., Au-Yeung, A., Berndt, A., Wallsworth, C., Horne, N., Gregorio, M., Mann, J. and Chaudhury, H. (2019), 'The benefits of and barriers to using a social robot PARO in care settings: a scoping review', *BMC Geriatr.* **19**(1), 232.
http://dx.doi.org/10.1186/s12877-019-1244-6

Hung, L., Mann, J., Perry, J., Berndt, A. and Wong, J. (2022), 'Technological risks and ethical implications of using robots in long-term care', *J. Rehabil. Assist. Technol. Eng.* **9**, 20556683221106917.
https://doi.org/10.1177/20556683221106917

Hutchins, E. (1995), *Cognition in the wild*, Cognition in the wild, The MIT Press, Cambridge, MA, US. Pages: xviii, 381.

Ipsen, S., Wulff, D., Kuhlemann, I., Schweikard, A. and Ernst, F. (2021), 'Towards automated ultrasound imaging-robotic image acquisition in liver and prostate for long-term motion monitoring', *Phys. Med. Biol.* **66**(9), 094002.
http://dx.doi.org/10.1088/1361-6560/ABF277

Jezernik, S., Colombo, G., Keller, T., Frueh, H. and Morari, M. (2003), 'Robotic orthosis lokomat: a rehabilitation and research tool', *Neuromodulation* **6**(2), 108–115.

Johannesson, P. and Perjons, E. (2021), *An Introduction to Design Science*, Springer International Publishing, Cham.
https://link.springer.com/10.1007/978-3-030-78132-3

Johnson, M. J., Loureiro, R. C. V. and Harwin, W. S. (2008), 'Collaborative tele-rehabilitation and robot-mediated therapy for stroke rehabilitation at home or clinic', *Intell. Serv. Robot.* **1**(2), 109–121.
http://dx.doi.org/10.1007/s11370-007-0010-3

Judy, L. M., Morrow, C. and Seo, N. J. (2023), 'Development and evaluation of an efficient training program to facilitate the adoption of a novel neurorehabilitation device', *J Rehabil Assist Technol Eng* **10**, 20556683231158552.

Jung, S., Moon, Y., Kim, J. and Kim, K. (2023), 'Deep neural network-based visual feedback system for nasopharyngeal swab sampling', *Sensors (Basel)* **23**(20), 8443. http://dx.doi.org/10.3390/S23208443

Kamani, E., Kalisz, D. E. and Szyran-Resiak, A. (2023), 'Patients' behavioral intentions toward robotic adoption in healthcare: An approach on apprehension of embedding robotics', *J. Gen. Manag.* **48**(4), 370–385. http://dx.doi.org/10.1177/03063070221080008

Kan, T.-S., Cheng, K.-J., Liu, Y.-F., Wang, R., Zhu, W.-D., Zhu, F.-D., Jiang, X.-F. and Dong, X.-T. (2022), 'Evaluation of a custom-designed human-robot collaboration control system for dental implant robot', *Int. J. Med. Robot.* **18**(1), e2346. http://dx.doi.org/10.1002/RCS.2346

Kemp, T., Ayton, J., Butler-Henderson, K. and Lam, M. (2024), 'Using sociotechnical systems theory to study the health information management workforce in Australian acute hospitals', *Social Theory and Health* **22**(4), 285–300. https://www.scopus.com/pages/publications/85210429122

Keraustret, Y., Di Rienzo, F., Eyssautier, C. and Guillot, A. (2024), 'Comparative efficacy of robotic and manual massage interventions on performance and well-being: A randomized crossover trial', *Sports Health* **16**(4), 650–660. http://dx.doi.org/10.1177/19417381231190869

Klebbe, R. and Friese, C. (2025), 'Exploring the role of robots in inpatient care: Caregivers´ perspectives on the development and evaluation of collaborative robot applications – A qualitative research approach', *Int. J. Soc. Robot.* pp. 1–18. http://dx.doi.org/10.1007/s12369-025-01270-1

Klebbe, R., Scherzinger, S. and Eicher, C. (2022), 'Assistive robots for patients with amyotrophic lateral sclerosis: Exploratory task-based evaluation study with an early-stage demonstrator', *JMIR Rehabil. Assist. Technol.* **9**(3), e35304. http://dx.doi.org/10.2196/35304

Klein, L. (2014), 'What do we actually mean by 'sociotechnical'? On values, boundaries and the problems of language', *Applied Ergonomics* **45**(2, Part A), 137–142.

Koh, W. Q., Toomey, E., Flynn, A. and Casey, D. (2022), 'Determinants of implementing of pet robots in nursing homes for dementia care', *BMC Geriatr.*

22(1), 457.
http://dx.doi.org/10.1186/s12877-022-03150-z

Koszulinski, A., Sandoval, J., Vendeuvre, T., Zeghloul, S. and Laribi, M. A. (2022), ‘Comanipulation robotic platform for spine surgery with exteroceptive visual coupling: Development and experimentation’, *J. Med. Device.* **16**(4).
http://dx.doi.org/10.1115/1.4054550

Kowalski, C., Arizpe-Gomez, P., Fifelski, C., Brinkmann, A. and Hein, A. (2020), ‘Design of a supportive transfer robot system for caregivers to reduce physical strain during nursing activities’, *Stud. Health Technol. Inform.* **270**, 1245–1246.
http://dx.doi.org/10.3233/SHTI200384

Kyrarini, M., Lygerakis, F., Rajavenkatanarayanan, A., Sevastopoulos, C., Nambiappan, H. R., Chaitanya, K. K., Babu, A. R., Mathew, J. and Makedon, F. (2021), ‘A survey of robots in healthcare’, *Technologies (Basel)* **9**(1), 8.
https://www.mdpi.com/2227-7080/9/1/8

Leavy, P. (2022), ‘Research design: Quantitative, qualitative, mixed methods, arts-based, and community-based participatory research approaches’.

Lecointre, L., Verde, J., Goffin, L., Venkatasamy, A., Seeliger, B., Lodi, M., Swanström, L. L., Akladios, C. and Gallix, B. (2022), ‘Robotically assisted augmented reality system for identification of targeted lymph nodes in laparoscopic gynecological surgery: a first step toward the identification of sentinel node : Augmented reality in gynecological surgery: Augmented reality in gynecological surgery’, *Surg. Endosc.* **36**(12), 9224–9233.
http://dx.doi.org/10.1007/S00464-022-09409-1

Lehmann, T., Sloboda, R., Usmani, N. and Tavakoli, M. (2018), ‘Human–machine collaboration modalities for semi-automated needle insertion into soft tissue’, *IEEE Robot. Autom. Lett.* **3**(1), 477–483.
http://dx.doi.org/10.1109/LRA.2017.2768123

Li, J., Sun, W., Gu, X., Guo, J., Ota, J., Huang, Z. and Zhang, Y. (2023), ‘A method for a compliant robot arm to perform a bandaging task on a swaying arm: A proposed approach’, *IEEE Robot. Autom. Mag.* **30**(1), 50–61.
http://dx.doi.org/10.1109/MRA.2022.3228501

Li, X., Li, M., Sun, H., Gong, J., Zhang, Z. and Zhang, R. (2020), ‘Establishing the improved dynamic model for the extracorporeal ultrasonic lithotripsy medical

cooperative robot', *Math. Probl. Eng.* **2020**, 1–10.
http://dx.doi.org/10.1155/2020/9752040

Licklider, J. C. R. (1960), 'Man-Computer Symbiosis', *IRE Trans. Hum. Factors Electron.* **HFE-1**(1), 4–11.

Lienenbrink, S., Behrens, J., Paluch, R., Müller, C., Agraz, C. N., Biedermann, H., Eichelberg, M., Fricke, C., Garthaus, M., Hein, A., Hoferichter, J., Meyer, S., Seefeldt, D. and Hülsken-Giesler, M. (2025), 'READY? – Reflective dialog tool on issues relating to the use of robotic systems for nursing care', *i-com* **24**(1), 243–258.

Lim, H., Matsumoto, N., Cho, B., Hong, J., Yamashita, M., Hashizume, M. and Yi, B.-J. (2016), 'Semi-manual mastoidectomy assisted by human-robot collaborative control - A temporal bone replica study', *Auris Nasus Larynx* **43**(2), 161–165.
http://dx.doi.org/10.1016/J.ANL.2015.08.008

Liu, K. and Tao, D. (2022), 'The roles of trust, personalization, loss of privacy, and anthropomorphism in public acceptance of smart healthcare services', *Comput. Human Behav.* **127**(107026), 107026.
http://dx.doi.org/10.1016/j.chb.2021.107026

Liu, Y., Caldwell, G., Rittenbruch, M., Teixeira, M. B. F., Burden, A. and Guertler, M. (2024), 'What Affects Human Decision Making in Human–Robot Collaboration?: A Scoping Review', *Robotics* **13**(2).
https://www.mdpi.com/2218-6581/13/2/30

Lo, K., Stephenson, M. and Lockwood, C. (2020), 'Adoption of robotic stroke rehabilitation into clinical settings: a qualitative descriptive analysis', *JBI Evid Implement* **18**(4), 376–390.

Luciani, B., Braghin, F., Pedrocchi, A. L. G. and Gandolla, M. (2023), 'Technology acceptance model for exoskeletons for rehabilitation of the upper limbs from therapists' perspectives', *Sensors (Basel)* **23**(3), 1721.
https://www.mdpi.com/1424-8220/23/3/1721

Luo, C., Yang, C., Yuan, R., Liu, Q., Li, P. and He, Y. (2024), 'Barriers and facilitators to technology acceptance of socially assistive robots in older adults - A qualitative study based on the capability, opportunity, and motivation behavior model (COM-B) and stakeholder perspectives', *Geriatr. Nurs.* **58**, 162–170.
http://dx.doi.org/10.1016/j.gerinurse.2024.05.025

Lv, H., Yang, G., Zhou, H., Huang, X., Yang, H. and Pang, Z. (2020), 'Teleoperation

of collaborative robot for remote dementia care in home environments', *IEEE J. Transl. Eng. Health Med.* **8**, 1400510.
`http://dx.doi.org/10.1109/JTEHM.2020.3002384`

Lyons, P. G., Edelson, D. P. and Churpek, M. M. (2018), 'Rapid response systems', *Resuscitation* **128**, 191–197.
`https://www.sciencedirect.com/science/article/pii/S0300957218302247`

Madi, M., Nielsen, S., Schweitzer, M., Siebert, M., Körner, D., Langensiepen, S., Stephan, A. and Meyer, G. (2024), 'Acceptance of a robotic system for nursing care: a cross-sectional survey with professional nurses, care recipients and relatives', *BMC Nurs.* **23**(1), 179.
`http://dx.doi.org/10.1186/s12912-024-01849-5`

Matheson, E., Minto, R., Zampieri, E. G. G., Faccio, M. and Rosati, G. (2019), 'Human–robot collaboration in manufacturing applications: A review', *Robotics* **8**(4), 100.
`https://www.mdpi.com/2218-6581/8/4/100`

Mathew, R., McGee, R., Roche, K., Warreth, S. and Papakostas, N. (2022), 'Introducing mobile collaborative robots into bioprocessing environments: Personalised drug manufacturing and environmental monitoring', *Appl. Sci. (Basel)* **12**(21), 10895.
`http://dx.doi.org/10.3390/app122110895`

Maxcy, S. J. (2003), 'Pragmatic threads in mixed methods research in the social sciences: The search for multiple modes of inquiry and the end of the philosophy of formalism', *Handbook of mixed methods in social and behavioral research* (51-89).

McCradden, M. D., Joshi, S., Anderson, J. A. and London, A. J. (2023), 'A normative framework for artificial intelligence as a sociotechnical system in healthcare', *Patterns (N. Y.)* **4**(11), 100864.
`http://dx.doi.org/10.1016/j.patter.2023.100864`

Melkas, H., Hennala, L., Pekkarinen, S. and Kyrki, V. (2020), 'Impacts of robot implementation on care personnel and clients in elderly-care institutions', *Int. J. Med. Inform.* **134**(104041), 104041.
`http://dx.doi.org/10.1016/j.ijmedinf.2019.104041`

Meskó, B., Hetényi, G. and Győrffy, Z. (2018), 'Will artificial intelligence solve the human resource crisis in healthcare?', *BMC Health Serv. Res.* **18**(1), 545.

https://bmchealthservres.biomedcentral.com/articles/10.1186/s12913-018-3359-4

Mocan, B., Mocan, M., Fulea, M., Murar, M. and Feier, H. (2022), 'Home-based robotic upper limbs cardiac telerehabilitation system', *Int. J. Environ. Res. Public Health* **19**(18), 11628.
http://dx.doi.org/10.3390/IJERPH191811628

Mora, F. (2012), 'The demise of Google Health and the future of personal health records', *International Journal of Healthcare Technology and Management* **13**(5-6), 363–377.

Morgan, D. L. (2007), 'Paradigms lost and pragmatism regained: Methodological implications of combining qualitative and quantitative methods', *J. Mix. Methods Res.* **1**(1), 48–76.
http://dx.doi.org/10.1177/2345678906292462

Morgan, D. L. (2014), 'Pragmatism as a paradigm for social research', *Qual. Inq.* **20**(8), 1045–1053.
http://dx.doi.org/10.1177/1077800413513733

Morrow, C. M., Johnson, E., Simpson, K. N. and Seo, N. J. (2021), 'Determining Factors that Influence Adoption of New Post-Stroke Sensorimotor Rehabilitation Devices in the USA', *IEEE Trans Neural Syst Rehabil Eng* **29**, 1213–1222.

Moulaei, K., Bahaadinbeigy, K., Haghdoostd, A. A., Nezhad, M. S. and Sheikhtaheri, A. (2023), 'Overview of the role of robots in upper limb disabilities rehabilitation: a scoping review', *Archives of Public Health* **81**(1), 84.
https://doi.org/10.1186/s13690-023-01100-8

Mumford, E. (2000), 'A Socio-Technical Approach to Systems Design', *Requirements Engineering* **5**(2), 125–133.
https://doi.org/10.1007/PL00010345

Nam, K. Y., Kim, H. J., Kwon, B. S., Park, J.-W., Lee, H. J. and Yoo, A. (2017), 'Robot-assisted gait training (Lokomat) improves walking function and activity in people with spinal cord injury: a systematic review', *Journal of NeuroEngineering and Rehabilitation* **14**(1), 24.
https://doi.org/10.1186/s12984-017-0232-3

Naneva, S., Sarda Gou, M., Webb, T. L. and Prescott, T. J. (2020), 'A systematic review of attitudes, anxiety, acceptance, and trust towards social robots', *Int. J.*

Soc. Robot. **12**(6), 1179–1201.
https://doi.org/10.1007/s12369-020-00659-4

Nilsen, P. (2015), 'Making sense of implementation theories, models and frameworks', *Implementation science: IS* **10**, 53.

Ohneberg, C., Stöbich, N. and Eberl, I. (2025), 'Possible applications and conditions for the development and integration of robotic assistance systems in the acute inpatient setting from the perspective of nursing professionals: A qualitative study', *Int. J. Soc. Robot.* pp. 1–15.
http://dx.doi.org/10.1007/s12369-025-01289-4

Organisation for Economic Co-operation and Development (2024), 'OECD AI Principles Overview'.
https://oecd.ai/en/ai-principles

Parak, R. and Juricek, M. (2022), 'Intelligent sampling of anterior human nasal swabs using a collaborative robotic arm', *Mendel* **28**(1), 32–40.
http://dx.doi.org/10.13164/mendel.2022.1.032

Park, Y.-H., Lee, D.-H. and Lee, J.-H. (2024), 'A Comprehensive Review: Robot-Assisted Treatments for Gait Rehabilitation in Stroke Patients', *Medicina (Kaunas)* **60**(4), 620.

Pasmore, W., Petee, J. and Bastian, R. (1986), 'Sociotechnical Systems in Health Care: A Field Experiment', *The Journal of Applied Behavioral Science* **22**(3), 329–339.
https://doi.org/10.1177/002188638602200311

Patton, M. Q. (1990), *Qualitative evaluation and research methods, 2nd ed*, Qualitative evaluation and research methods, 2nd ed, Sage Publications, Inc, Thousand Oaks, CA, US. Pages: 532.

Pavlou, P. A. (2003), 'Consumer acceptance of electronic commerce: Integrating trust and risk with the technology acceptance model', *Int. J. Electron. Commer.* **7**(3), 101–134.
https://doi.org/10.1080/10864415.2003.11044275

Peffers, K., Tuunanen, T., Rothenberger, M. A. and Chatterjee, S. (2007), 'A Design Science Research Methodology for Information Systems Research', *Journal of Management Information Systems* **24**(3), 45–77. _eprint: https://doi.org/10.2753/MIS0742-1222240302.
https://doi.org/10.2753/MIS0742-1222240302

Peshkin, M. and Colgate, J. E. (1999), 'Cobots', *Industrial Robot: the international journal of robotics research and application* **26**(5), 335–341.
https://doi.org/10.1108/01439919910283722

Prendergast, J. M., Balvert, S., Driessen, T., Seth, A. and Peternel, L. (2021), 'Biomechanics aware collaborative robot system for delivery of safe physical therapy in shoulder rehabilitation', *IEEE Robot. Autom. Lett.* **6**(4), 7177–7184.
http://dx.doi.org/10.1109/LRA.2021.3097375

Qiao, S.-C., Wu, X.-Y., Shi, J.-Y., Tonetti, M. S. and Lai, H.-C. (2023), 'Accuracy and safety of a haptic operated and machine vision controlled collaborative robot for dental implant placement: A translational study', *Clin. Oral Implants Res.* **34**(8), 839–849.
http://dx.doi.org/10.1111/CLR.14112

Qu, Q., Lin, Y., He, Z., Fu, J., Zou, F., Jiang, Z., Guo, F. and Jia, J. (2021), 'The effect of applying robot-assisted task-oriented training using human-robot collaborative interaction force control technology on upper limb function in stroke patients: Preliminary findings', *Biomed Res. Int.* **2021**, 9916492.
http://dx.doi.org/10.1155/2021/9916492

Quiles, E., Dadone, J., Chio, N. and García, E. (2022), 'Cross-platform implementation of an SSVEP-based BCI for the control of a 6-DOF robotic arm', *Sensors (Basel)* **22**(13), 5000.
http://dx.doi.org/10.3390/S22135000

Rasmussen, M. K., Schneider-Kamp, A., Hyrup, T. and Godono, A. (2024), 'New colleague or gimmick hurdle? A user-centric scoping review of the barriers and facilitators of robots in hospitals', *PLOS Digit. Health* **3**(11), e0000660.
http://dx.doi.org/10.1371/journal.pdig.0000660

Reicherzer, L., Scheermesser, M., Kläy, A., Duarte, J. E. and Graf, E. S. (2024), 'Barriers and facilitators to the use of wearable robots as assistive devices: Qualitative study with older adults and physiotherapists', *JMIR Rehabil. Assist. Technol.* **11**(1), e52676.
http://dx.doi.org/10.2196/52676

Rigaud, A.-S., Dacunha, S., Harzo, C., Lenoir, H., Sfeir, I., Piccoli, M. and Pino, M. (2024), 'Implementation of socially assistive robots in geriatric care institutions: Healthcare professionals' perspectives and identification of facilitating factors and barriers', *J. Rehabil. Assist. Technol. Eng.* **11**, 20556683241284765. Publisher:

SAGE PublicationsSage UK: London, England.
http://dx.doi.org/10.1177/20556683241284765

Ringle, C. M., Wende, S. and Becker, J.-M. (2024), 'SmartPLS'.
https://www.smartpls.com

Riva, L., Pagani, R., Fiorentino, A., Borboni, A. and Ceretti, E. (2022), 'Preliminary study for the development of an autonomous system for emulating mandibular bone drilling', *Int. J. Mechatron. Manuf. Syst.* **15**(2/3), 185.
http://dx.doi.org/10.1504/ijmms.2022.124923

Saadatzi, M. N., Logsdon, M. C., Abubakar, S., Das, S., Jankoski, P., Mitchell, H., Chlebowy, D. and Popa, D. O. (2020), 'Acceptability of using a robotic nursing assistant in health care environments: Experimental pilot study', *J. Med. Internet Res.* **22**(11), e17509.
https://www.jmir.org/2020/11/e17509

Salwei, M. E. and Carayon, P. (2022), 'A sociotechnical systems framework for the application of artificial intelligence in health care delivery', *J. Cogn. Eng. Decis. Mak.* **16**(4), 194–206.
https://journals.sagepub.com/doi/abs/10.1177/15553434221097357

Sandoval, J., Laribi, M. A., Faure, J.-P., Breque, C., Richer, J.-P. and Zeghloul, S. (2021), 'Towards an autonomous robot-assistant for laparoscopy using exteroceptive sensors: Feasibility study and implementation', *IEEE Robot. Autom. Lett.* **6**(4), 6473–6480.
http://dx.doi.org/10.1109/LRA.2021.3094644

Seeber, I., Bittner, E., Briggs, R. O., de Vreede, T., de Vreede, G.-J., Elkins, A., Maier, R., Merz, A. B., Oeste-Reiß, S., Randrup, N., Schwabe, G. and Söllner, M. (2020), 'Machines as teammates: A research agenda on AI in team collaboration', *Information & Management* **57**(2), 103174.
https://www.sciencedirect.com/science/article/pii/S0378720619303337

Sekhon, M., Cartwright, M. and Francis, J. J. (2017), 'Acceptability of healthcare interventions: an overview of reviews and development of a theoretical framework', *BMC health services research* **17**(1), 88.

Servaty, R., Kersten, A., Brukamp, K., Möhler, R. and Mueller, M. (2020), 'Implementation of robotic devices in nursing care. Barriers and facilitators: an integrative review', *BMJ Open* **10**(9), e038650.
http://dx.doi.org/10.1136/bmjopen-2020-038650

Shachak, A., Kuziemsky, C. and Petersen, C. (2019), 'Beyond TAM and UTAUT: Future directions for HIT implementation research', *J. Biomed. Inform.* **100**(103315), 103315.
http://dx.doi.org/10.1016/j.jbi.2019.103315

Simeoni, R., Colonnelli, F., Eutizi, V., Marchetti, M., Paolini, E., Papalini, V., Punturo, A., Salvò, A., Scipinotti, N., Serpente, C., Barbini, E., Troscia, R., Maccioni, G. and Giansanti, D. (2021), 'The social robot and the digital physiotherapist: Are we ready for the team play?', *Healthcare (Basel)* **9**(11), 1454.
http://dx.doi.org/10.3390/HEALTHCARE9111454

Sittig, D. F. and Singh, H. (2010), 'A new sociotechnical model for studying health information technology in complex adaptive healthcare systems', *Quality & Safety in Health Care* **19 Suppl 3**(Suppl 3), i68–74.

Sittig, D. F., Wright, A., Coiera, E., Magrabi, F., Ratwani, R., Bates, D. W. and Singh, H. (2020), 'Current challenges in health information technology-related patient safety', *Health Informatics J.* **26**(1), 181–189.
http://dx.doi.org/10.1177/1460458218814893

So, J.-H., Sobucki, S., Szewczyk, J., Marturi, N. and Tamadazte, B. (2022), 'Shared control schemes for middle ear surgery', *Front. Robot. AI* **9**, 824716.
http://dx.doi.org/10.3389/FROBT.2022.824716

Song, J., Sridhar, R. I., Rogers, D. M., Hiddleson, C., Davis, C., Holden, T. L., Ramsey-Haynes, S., Reif, L., Swann, J., Jabaley, C. S., Gullatte, M. and Kamaleswaran, R. (2025), 'Clinicians' perceptions and potential applications of robotics for task automation in critical care: Qualitative study', *J. Med. Internet Res.* **27**(1), e62957.
http://dx.doi.org/10.2196/62957

Spil, T. and Klein, R. (2014), Personal health records success: Why Google health failed and what does that mean for Microsoft HealthVault?, IEEE, pp. 2818–2827.

Stahl, B. C. and Coeckelbergh, M. (2016), 'Ethics of healthcare robotics: Towards responsible research and innovation', *Rob. Auton. Syst.* **86**, 152–161.
https://www.sciencedirect.com/science/article/pii/S0921889016305292

Stasevych, M. and Zvarych, V. (2023), 'Innovative robotic technologies and artificial intelligence in pharmacy and medicine: Paving the way for the future of health care—A review', *Big Data Cogn. Comput.* **7**(3), 147.
https://www.mdpi.com/2504-2289/7/3/147

Sunny, M. S. H., Zarif, M. I. I., Rulik, I., Sanjuan, J., Rahman, M. H., Ahamed, S. I., Wang, I., Schultz, K. and Brahmi, B. (2021), 'Eye-gaze control of a wheelchair mounted 6DOF assistive robot for activities of daily living', *J. Neuroeng. Rehabil.* **18**(1), 173.
`http://dx.doi.org/10.1186/S12984-021-00969-2`

Tashakkori, A. (2010), 'SAGE handbook of mixed methods in social & behavioral research'.

Tashakkori, A. and Teddlie, C. (2021), *Sage handbook of mixed methods in social & behavioral research*, SAGE publications.
`https://books.google.com/books?hl=en&lr=&id=fwc0EAAAQBAJ&oi=fnd&pg=PR3&dq=andbook+of+Mixed+Methods+in+Social+and+Behavioral+Research.+Thousand+Oaks:+Sage.&ots=8XAlpYHjGQ&sig=R7HvVpzJ04Tc-zEYheTxEi0homA`

Topol, E. J. (2019), 'High-performance medicine: the convergence of human and artificial intelligence', *Nature Medicine* **25**(1), 44–56.
`https://www.nature.com/articles/s41591-018-0300-7`

Tricco, A. C., Lillie, E., Zarin, W., O'Brien, K. K., Colquhoun, H., Levac, D., Moher, D., Peters, M. D. J., Horsley, T., Weeks, L., Hempel, S., Akl, E. A., Chang, C., McGowan, J., Stewart, L., Hartling, L., Aldcroft, A., Wilson, M. G., Garritty, C., Lewin, S., Godfrey, C. M., Macdonald, M. T., Langlois, E. V., Soares-Weiser, K., Moriarty, J., Clifford, T., Tuncalp, O. and Straus, S. E. (2018), 'PRISMA Extension for Scoping Reviews (PRISMA-ScR): Checklist and Explanation', *Annals of Internal Medicine* **169**(7), 467–473.

Trist, E. (1981), The Evolution of Socio-Technical Systems: A Conceptual Framework and an Action Research Program.

Trist, E. L. and Bamforth, K. W. (1951), 'Some Social and Psychological Consequences of the Longwall Method of Coal-Getting: An Examination of the Psychological Situation and Defences of a Work Group in Relation to the Social Structure and Technological Content of the Work System', *Human Relations* **4**(1), 3–38.
`https://doi.org/10.1177/001872675100400101`

Tucan, P., Vaida, C., Horvath, D., Caprariu, A., Burz, A., Gherman, B., Iakab, S. and Pisla, D. (2022), 'Design and experimental setup of a robotic medical instrument for brachytherapy in non-resectable liver tumors', *Cancers (Basel)*

14(23), 5841.
`http://dx.doi.org/10.3390/CANCERS14235841`

Turchetti, G., Vitiello, N., Trieste, L., Romiti, S., Geisler, E. and Micera, S. (2014), ‘Why effectiveness of robot-mediated neurorehabilitation does not necessarily influence its adoption’, *IEEE Rev Biomed Eng* **7**, 143–153.

United Nations (2015), THE 17 GOALS, Technical report.
`https://sdgs.un.org/goals`

Vallès-Peris, N., Barat-Auleda, O. and Domènech, M. (2021), ‘Robots in healthcare? What patients say’, *Int. J. Environ. Res. Public Health* **18**(18), 9933.
`http://dx.doi.org/10.3390/ijerph18189933`

Valori, M., Scibilia, A., Fassi, I., Saenz, J., Behrens, R., Herbster, S., Bidard, C., Lucet, E., Magisson, A., Schaake, L., Bessler, J., Prange-Lasonder, G. B., Kühnrich, M., Lassen, A. B., Nielsen, K., Valori, M., Scibilia, A., Fassi, I., Saenz, J., Behrens, R., Herbster, S., Bidard, C., Lucet, E., Magisson, A., Schaake, L., Bessler, J., Prange-Lasonder, G. B., Kühnrich, M., Lassen, A. B. and Nielsen, K. (2021), ‘Validating Safety in Human–Robot Collaboration: Standards and New Perspectives’, *Robotics* **10**(2). Company: Multidisciplinary Digital Publishing Institute Distributor: Multidisciplinary Digital Publishing Institute Institution: Multidisciplinary Digital Publishing Institute Label: Multidisciplinary Digital Publishing Institute.
`https://www.mdpi.com/2218-6581/10/2/65`

van Wynsberghe, A. and Li, S. (2019), ‘A paradigm shift for robot ethics: from HRI to human–robot–system interaction (HRSI)’, *Medicoleg. Bioeth.* **9**, 11–21.
`https://www.tandfonline.com/doi/abs/10.2147/MB.S160348`

Venkatesh, Morris, Davis and Davis (2003), ‘User acceptance of information technology: Toward a unified view’, *MIS Q* **27**(3), 425.
`https://www.jstor.org/stable/30036540`

Vichitkraivin, P. and Naenna, T. (2021), ‘Factors of healthcare robot adoption by medical staff in Thai government hospitals’, *Health Technol. (Berl.)* **11**(1), 139–151.
`https://doi.org/10.1007/s12553-020-00489-4`

Vitrani, M.-A., Marx, A., Iordache, R. Z., Muller, S. and Morel, G. (2015), ‘Robot guidance of an ultrasound probe toward a 3D region of interest detected through

X-ray mammography', *Int. J. Comput. Assist. Radiol. Surg.* **10**(12), 1893–1903. `http://dx.doi.org/10.1007/S11548-015-1244-8`

Wang, J., Zhang, X., Chen, X. and Song, Z. (2023), 'A touch-free human-robot collaborative surgical navigation robotic system based on hand gesture recognition', *Front. Neurosci.* **17**, 1200576. `http://dx.doi.org/10.3389/FNINS.2023.1200576`

Wang, Z., Liu, Z., Ma, Q., Cheng, A., Liu, Y.-H., Kim, S., Deguet, A., Reiter, A., Kazanzides, P. and Taylor, R. H. (2018), 'Vision-based calibration of dual RCM-based robot arms in human-robot collaborative minimally invasive surgery', *IEEE Robot. Autom. Lett.* **3**(2), 672–679. `http://dx.doi.org/10.1109/LRA.2017.2737485`

Wasic, C., Erzgräber, R., Unger-Büttner, M., Donath, C., Böhme, H.-J. and Graessel, E. (2024), 'What helps, what hinders?-Focus group findings on barriers and facilitators for mobile service robot use in a psychosocial group therapy for people with dementia', *Front. Robot. AI* **11**, 1258847. `http://dx.doi.org/10.3389/frobt.2024.1258847`

Wasić, C., Bahrmann, F., Vogt, S., Böhme, H.-J. and Graessel, E. (2022), Assessing professional caregivers' intention to use and relatives' support of use for a mobile service robot in group therapy for institutionalized people with dementia – A standardized assessment using an adapted version of UTAUT, *in* K. Miesenberger, G. Kouroupetroglou, K. Mavrou, R. Manduchi, M. Covarrubias Rodriguez and P. Penáz, eds, 'Lecture Notes in Computer Science', Vol. 13342 of *Lecture notes in computer science*, Springer International Publishing, Cham, pp. 247–256. `https://link.springer.com/10.1007/978-3-031-08645-8_29`

Webb, C. (1992), 'The use of the first person in academic writing: objectivity, language and gatekeeping', *Journal of Advanced Nursing* **17**(6), 747–752.

Weerarathna, I. N., Raymond, D. and Luharia, A. (2023), 'Human-robot collaboration for healthcare: A narrative review', *Cureus* **15**(11), e49210.

Wolański, W., Michnik, R., Suchoń, S., Burkacki, M., Chrzan, M., Zadoń, H., Szaflik, P., Szefler-Derela, J. and Wasiuk-Zowada, D. (2023), 'Analysis of the possibility of using the UR10e Cobot in neurological treatment', *Actuators* **12**(7), 268. `http://dx.doi.org/10.3390/act12070268`

Wong, J., Young, E., Hung, L., Mann, J. and Jackson, L. (2023), 'Beyond Plan-Do-Study-Act cycle - staff perceptions on facilitators and barriers to the implementa-

tion of telepresence robots in long-term care', *BMC Health Serv. Res.* **23**(1), 772.
http://dx.doi.org/10.1186/s12913-023-09741-9

Wong, K. L. Y., Hung, L., Wong, J., Park, J., Alfares, H., Zhao, Y., Mousavinejad, A., Soni, A. and Zhao, H. (2024), 'Adoption of artificial intelligence-enabled robots in long-term care homes by health care providers: Scoping review', *JMIR Aging* **7**, e55257.
http://dx.doi.org/10.2196/55257

World Health Organization (2022), 'World health statistics 2022: monitoring health for the SDGs, sustainable development goals'.
https://www.who.int/publications/i/item/9789240051157

World Health Organization (2025), *Global strategy on digital health 2020-2027*, World Health Organization.
https://books.google.com/books?hl=en&lr=&id=_DWcEQAAQBAJ&oi=fnd&pg=PA2&dq=Global+strategy+on+digital+health+2020-2025&ots=rVrJ9Bt2RY&sig=tMAm5vD5COg9dgFYVcHuXsIASWw

Xia, X., Li, T., Sang, S., Cheng, Y., Ma, H., Zhang, Q. and Yang, K. (2023), 'Path planning for obstacle avoidance of robot arm based on improved potential field method', *Sensors (Basel)* **23**(7), 3754.
http://dx.doi.org/10.3390/S23073754

Xing, B., He, Z., Zhou, F., Zhao, Y. and Shan, T. (2023), 'Automatic force-controlled 3D photoacoustic system for human peripheral vascular imaging', *Biomed. Opt. Express* **14**(2), 987–1002.
http://dx.doi.org/10.1364/BOE.481163

Xu, C., Lin, L., Aung, Z. M., Chen, X., Sun, M., Chai, G. and Xie, L. (2021), 'A preliminary study on animal experiments of robot-assisted craniotomy', *World Neurosurg.* **149**, e748–e757.
http://dx.doi.org/10.1016/J.WNEU.2021.01.108

Xu, S., Tu, D., He, Y., Tan, S. and Fang, M. (2014), 'ACT-R-typed human–robot collaboration mechanism for elderly and disabled assistance', *Robotica* **32**(5), 711–721.
http://dx.doi.org/10.1017/S0263574713001094

Yang, J., Barragan, J. A., Farrow, J. M., Sundaram, C. P., Wachs, J. P. and Yu, D. (2022), 'An adaptive human-robotic interaction architecture for augmenting surgery performance using real-time workload sensing-demonstration of a semi-

autonomous suction tool', *Hum. Factors* **66**(4), 1081–1102.
http://dx.doi.org/10.1177/00187208221129940

Yeoh, S. Y. and Chin, P. N. (2022), 'Exploring home health-care robots adoption in Malaysia: extending the UTAUT model', *Int. J. Pharm. Healthc. Mark.* **16**(3), 392–411.

Yin, R. K. (2025), 'Case Study Research and Applications'.
https://us.sagepub.com/en-us/nam/case-study-research-and-applications/book250150

Yip, H. M., Wang, Z., Navarro-Alarcon, D., Li, P., Cheung, T. H., Greiffenhagen, C. and Liu, Y.-H. (2020), 'A collaborative robotic uterine positioning system for laparoscopic hysterectomy: Design and experiments', *Int. J. Med. Robot.* **16**(4), e2103.
http://dx.doi.org/10.1002/rcs.2103

Appendix A

Empirical Literature on HRC in Healthcare: Methodology and Results

A.1 Methodology

In this research, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) guidelines were employed to ensure a structured and thorough review process (Tricco et al. 2018). The use of PRISMA-ScR guidelines ensures that the review is conducted in accordance with established methodological frameworks, enhancing the rigor and reliability of the findings (Tricco et al. 2018).

The study selection process is summarised in Figure A.1. The PRISMA-ScR flow diagram outlines the number of records identified, screened, excluded, and included at each stage of the review process.

A.1.1 Data Sources

The research involved an extensive literature search across databases known for their comprehensive coverage of both technological and healthcare subjects. These included IEEE Xplore, ACM Digital Library, ScienceDirect, Web of Science (WoS), and PubMed.

A.1.2 Search Strategy

The search strategy was designed to encompass a wide array of empirical studies pertaining to HRC in healthcare. The keywords and phrases were categorised into three distinct groups for a targeted approach. For HRC, terms such as “human-robot collaborat*”, “collaborative robot*”, and “cobot*” were used. The context of

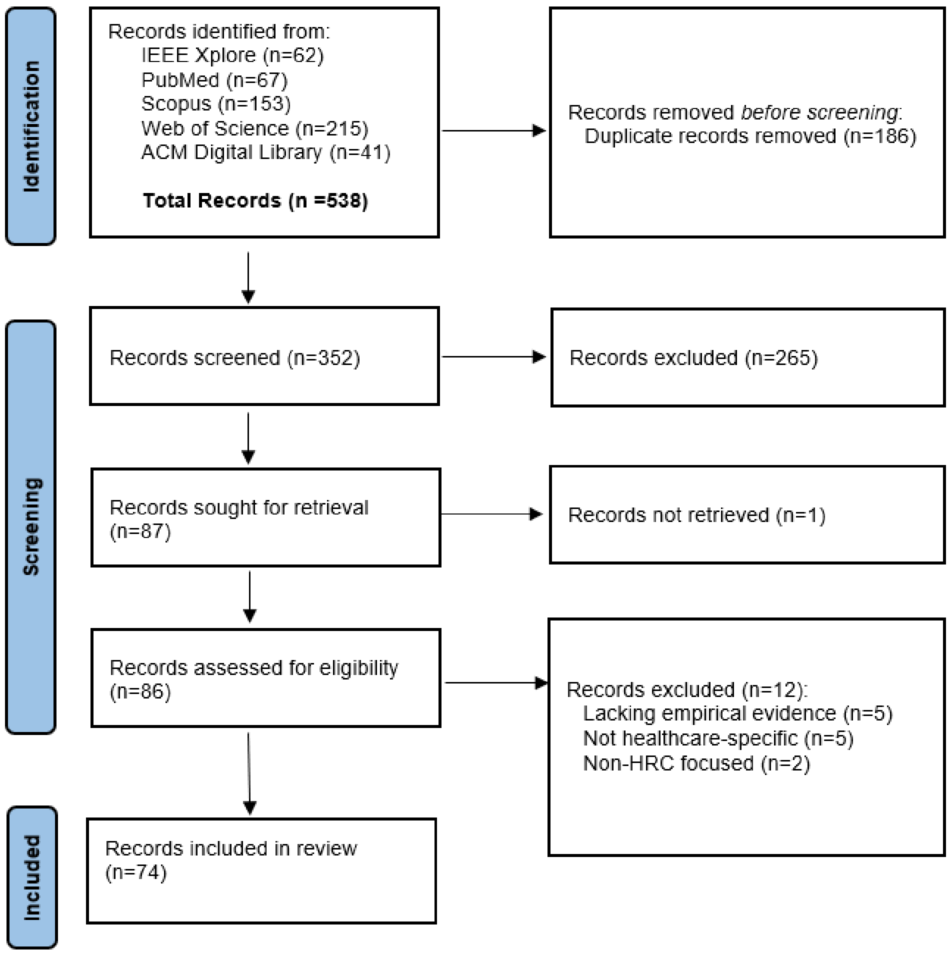

Figure A.1: PRISMA-ScR flow diagram showing the identification, screening, eligibility assessment, and inclusion of studies in the scoping review.

healthcare was represented by keywords such as “Health*”, “Care”, “Medical”, and “Rehabilitation”. The empirical nature of the studies was captured through terms such as “Empirical”, “Experiment*”, “Trial”, and “Stud*”. The search, carried out on 2 December 2023, yielded a total of 538 papers.

A.1.3 Study Selection

The study selection process involved a two-tier screening method. The initial review was based on title, abstract, and keywords, and was facilitated using the Rayyan.ai platform. This platform was used for identifying duplicates and highlighting relevant keywords. Removal of all 186 duplicates was manually confirmed, and a manual review of each study's title, abstract, and keywords was conducted to ensure accuracy and relevance.

Inclusion criteria focused on empirical research published in peer-reviewed journals, detailing the impacts of HRC in healthcare, reported in English with full-text availability. The exclusion criteria omitted research from conference proceedings, book chapters, magazines, news, and posters, as well as literature reviews and incomplete research that reported only HRC design without empirical results. This step reduced the pool to 87 studies.

The second stage entailed retrieving the full-text articles and conducting a comprehensive full-text review. Applying the same inclusion criteria with a more detailed analysis led to the elimination of 12 additional studies. After completing this process, 74 papers remained for detailed analysis. The specifics of this procedure are depicted in the flow chart provided in Fig. 1.

A.1.4 Data Extraction and Synthesis

Extracted data from the included studies were entered into an Excel spreadsheet. The data consisted of publication year, journal name, country of the study, healthcare application, robot model used, research setting, and primary focus areas. The initial analysis captured the content of each article using the authors' terminology, after which a framework of categories was created for each key element to facilitate a structured synthesis.

A.2 Results

In this section, we present the findings of our analysis, offering specific insights related to each element of our literature review. It is important to note that the focus of this study is exclusively on HRC in healthcare as an emerging research area. This focus influenced the dataset, leading to the exclusion of healthcare robotics studies not explicitly addressing HRC. For example, in the geographical distribution (Section 3.3), countries such as Japan are less prominent despite their leadership in healthcare robotics. Similarly, well-known robotic systems such as CyberKnife, the Mako Surgical System , and Lokomat are not included in the robot models discussed in Section 3.5. Therefore, the findings should not be interpreted as representative of healthcare robotics more broadly.

A.2.1 Publication Years

To gain insight into the evolution and current trends in HRC in healthcare, we analysed the publication years of the included studies. Among the 74 studies published between 2006 and 2023, a notable increase in publications was observed in recent years. Between 2021 and 2023, 50 studies were published, accounting for over 67% of the total. This surge underscores the contemporary relevance and rapid advancement of HRC in healthcare settings. Figure 2 illustrates the distribution of publications over time.

COVID-19 emerged as a major influencing factor in recent years. Since 2021, five studies focused specifically on developing HRC solutions for COVID-19 (Freeman et al. 2021; Jung et al. 2023; Colucci et al. 2021; Deniz and Gökmen 2021; Parak and Juricek 2022). Three additional studies acknowledged COVID-19 as a significant driver of HRC research in healthcare (Simeoni et al. 2021; Klebbe et al. 2022; Mocan et al. 2022).

A.2.2 Publication Journals

To grasp the broad and multidisciplinary nature of HRC research in healthcare, we analysed the journals in which the selected articles were published. Our examination of the 74 included articles revealed a distribution across 56 distinct journals. Notably, the journals with the highest number of publications in this field are *Sensors*, with seven articles, followed by *IEEE Robotics and Automation Letters*, with six articles. Table 1 presents the journals and the corresponding number of papers published in each.

The 46 journals with a single publication listed in Table 1 span a wide range of disciplines. Within the robotics and automation domain, journals such as *IEEE Robotics and Automation Magazine* and *Robotics and Autonomous Systems* are represented. In the health sciences, examples include *Biomed Research International* and *Clinical*

Table A.1: Distribution of publications across journals

Journal	**Number of papers**
Sensors	7
IEEE Robotics and Automation Letters	6
Frontiers in Robotics and AI	3
Journal of NeuroEngineering and Rehabilitation	2
International Journal of Medical Robotics and Computer Assisted Surgery	2
Machines	2
IEEE Access	2
IEEE Transactions on Automation Science and Engineering	2
International Journal of Computer Assisted Radiology and Surgery	2
Journals with one publication*	46

Oral Implants Research. Engineering-focused journals include *Mathematical Problems in Engineering* and *Engineering Studies*, while the human factors discipline is represented by journals such as *Applied Ergonomics* and *Human Factors*.

The diversity of publication venues reflects the multifaceted nature of HRC research in healthcare. This breadth, spanning technology, engineering, healthcare, and human interaction, illustrates the wide scope of the field. While a substantial portion of the literature focuses on technological and engineering developments, indicating ongoing advances in HRC systems, the presence of studies in specialised healthcare journals signals growing recognition of HRC's potential clinical relevance.

A.2.3 Geographical Distribution of Research

To understand the global reach of HRC research in healthcare, we analysed the geographical distribution of the studies. The distribution was derived from the study locations reported in the articles and is summarised in Table 2. In cases where the country of research was not explicitly stated, alternative indicators—such as funding sources, grant acknowledgements, or the authority providing ethics approval—were used to infer the study location. When these details were unavailable, the affiliation of the first author was used.

In one exceptional case (Johnson et al. 2008), a study involved a tele-rehabilitation system operating simultaneously in both the USA and the UK; therefore, both countries were included in the analysis for that paper. The results demonstrate a broad international contribution, with China leading the number of publications, followed by the USA, Italy, and Germany. Several European countries, including France, Spain, and the UK, also show substantial engagement in this research area.

Table A.2: Number of publications by country in the selected papers

Country	**Publication count**
China	16
USA	9
Italy	6
Germany	6
France	5
Spain	5
UK	4
Republic of Korea	3
Romania	3
Canada	3
Japan	2
Turkey	2
Countries with one publication*	18

**Countries with one publication include Czech Republic, Hungary, Ireland, Israel, Malaysia, Netherlands, Poland, Portugal, Russia, Slovenia, and Taiwan.*

The geographical distribution highlights the worldwide interest and relevance of HRC in healthcare. However, as discussed earlier (see Section 3), some countries with strong reputations in robotics research, such as Japan, appear underrepresented in this dataset. This discrepancy may be attributed to the specific focus of this review on HRC rather than healthcare robotics more broadly, as well as to a stronger emphasis in some regions on technological development rather than on interactive and collaborative human–robot relationships.

Robotic Platforms and System Characteristics

To understand the predominant types of robots used for HRC in healthcare, I analysed the specific robot models and their associated application domains. A.3 provides an overview of the main robot brands identified in the dataset, their representative models, and the healthcare application areas in which they are employed.

Figure A.2 shows examples of collaborative robots that appear frequently in the reviewed studies.

Table A.3: Robot brands, representative models, and application domains

Robot brand	Models	Application domains	Examples
Universal Robots	UR3e, UR5e, UR10e	Robot-assisted surgery; rehabilitation and mobility assistance; diagnostic and interventional support	(Jung et al. 2023; Parak and Juricek 2022; Fontúrbel et al. 2023; Lecointre et al. 2022)
KUKA Robotics	LBR iiwa series	Robot-assisted surgery; rehabilitation and mobility assistance; assistive robotics and social care	(Prendergast et al. 2021; Kowalski et al. 2020; Tucan et al. 2022; Ipsen et al. 2021; Mathew et al. 2022)
Franka Emika	Panda robot	Robot-assisted surgery; diagnostic and interventional support	(Klebbe et al. 2022; Sandoval et al. 2021; Koszulinski et al. 2022; Keraútret et al. 2024)
da Vinci Research Kits	da Vinci Research Kit (dVRK)	Robot-assisted surgery	(Hu et al. 2023; Yang et al. 2022; Wang et al. 2018)
Miscellaneous	MARSE, KineAssist, Sawyer, and others	Rehabilitation; assistive care; biomanufacturing	(Freeman et al. 2021; Brahmi et al. 2021, 2019; Dionisio and Brown 2016)

(a) KUKA LBR iiwa

(b) Franka Emika Panda

(c) Universal Robots UR3e

Figure A.2: Representative robotic platforms frequently used in the reviewed studies. Images reproduced from official manufacturer websites for illustrative purposes.

Appendix B

Exploratory Expert Insights: Codebook

Category	Code	Description
Financial Models and Funding Mechanisms	Funding limitations hinder early user experience design	Notes that available funding for research and development is insufficient to adequately support early-stage user experience design.
Financial Models and Funding Mechanisms	Administrative focus prioritizes economic impact over user experience	Notes that administrative bodies prioritize the economic impact on the healthcare budget when making purchase decisions, neglecting user experience and design considerations.
Financial Models and Funding Mechanisms	Addressing staffing shortages through technological solutions	Explores using automation or robotics to help cover staffing shortages and reduce workload.
Financial Models and Funding Mechanisms	Cost-effectiveness of robotic rehabilitation	Considering the financial implications of using robotic devices in rehabilitation, highlighting the potential for reduced labor costs and efficiency gains.
Financial Models and Funding Mechanisms	Navigating complex public funding and procurement processes	Acknowledges the intricate and lengthy process required to secure funding and procure robotic equipment within the public service.
Financial Models and Funding Mechanisms	Collaboration with robotic engineers for research funding	Mention of collaborating with a robotic engineer, Shahid Hussain, at UC, and actively seeking funding for research on an ankle robot.
Financial Models and Funding Mechanisms	Optimizing resource utilization through continuous operation	Desire to maximize the return on investment for new equipment by ensuring consistent and full utilization.
Financial Models and Funding Mechanisms	Robotics offer a long-term financially viable solution for rehabilitation	Belief that robotics presents a financially attractive alternative to traditional staffing models, potentially offering long-term cost savings and improved patient outcomes.

Category	Code	Description
Financial Models and Funding Mechanisms	Medical device failure often stems from imbalance in performance axes	Discusses a researcher's findings on medical device startups.
Financial Models and Funding Mechanisms	Significant financial investment is essential for medical device development	Emphasizes the substantial financial resources required for medical device development, encompassing engineering, prototyping, cloud computing, clinical trials, regulatory submissions, and securing reimbursement.
Financial Models and Funding Mechanisms	Long development timelines are characteristic of implantable and power technologies	Highlights the extended development timelines associated with implantable and power technologies.
Financial Models and Funding Mechanisms	Strategic connections are crucial for company success	Highlights the critical role of establishing connections across clinical, business, and political domains for a company's progress.
Financial Models and Funding Mechanisms	Investor expectations prioritize financial returns over clinical performance	Notes that the pressure from investors to achieve financial returns often overshadows the focus on achieving optimal clinical performance.
Financial Models and Funding Mechanisms	Regulatory environment favors established corporations	Notes that the current regulatory environment inadvertently favors large, established corporations with the resources to navigate complex regulations and engage in lobbying.
Financial Models and Funding Mechanisms	User-centric design is sidelined by regulatory pressures	Notes that the initial focus on user needs and iterative design often diminishes as companies face regulatory requirements and financial pressures.
Financial Models and Funding Mechanisms	Startups rarely follow through the full product lifecycle	
Financial Models and Funding Mechanisms	Economic considerations influencing AI adoption hesitancy	Notes that economic factors play a role in the hesitancy surrounding AI adoption in healthcare.
Financial Models and Funding Mechanisms	Financial considerations impact risk mitigation strategies	Highlights a conflict between cost-saving measures and the ability to secure adequate liability insurance.
Financial Models and Funding Mechanisms	Alignment of evaluation metrics with business goals and needs	Prioritizing the alignment of evaluation metrics and goals with broader business objectives and customer needs.
Financial Models and Funding Mechanisms	Understanding the need for broader considerations in technology adoption	Recognizes that successful technology adoption requires factors beyond those typically included in research projects.

Category	Code	Description
Financial Models and Funding Mechanisms	Understanding the user-buyer disparity in healthcare technology adoption	Highlights the critical distinction between the user of a healthcare technology and the entity responsible for payment.
Financial Models and Funding Mechanisms	Different stakeholders, different success criteria	Reflects on the administrator's focus on quantifiable benefits, specifically highlighting the reduction in human resource costs as a key metric for adoption.
Financial Models and Funding Mechanisms	Financial viability is a prerequisite for technology adoption	Notes that technology implementation requires financial justification.
Financial Models and Funding Mechanisms	Government funding through Medicare codes facilitates adoption	Notes that existing government funding mechanisms, such as Medicare codes.
Financial Models and Funding Mechanisms	Economic considerations influence technology adoption	Notes that economic factors, such as administrator willingness to pay and cost savings.
Individuals and Stakeholders	Lack of consultation in device design phase	Reflects on the absence of frontline healthcare provider input during the design phase of medical devices.
Individuals and Stakeholders	Device development operates within isolated silos	Notes that device developers adhere to separate regulatory standards.
Individuals and Stakeholders	Collaboration with manufacturers informs design iteration	Seeks input from established manufacturers, such as ResMed, during the design phase to refine and improve the technology.
Individuals and Stakeholders	Ignorance of human-machine interaction in intensive care	Notes a lack of awareness and understanding regarding human-machine interaction principles within the healthcare system, in ICU settings.
Individuals and Stakeholders	The need for robotics to augment care	Highlights a perceived turning point in the integration of robotics into healthcare delivery.
Individuals and Stakeholders	Building trust through transparency and occasional inspection of AI operations	Notes that trust in AI systems is built through transparency and the ability to occasionally inspect their operations.
Individuals and Stakeholders	Resistance to change due to established comfort and familiarity with existing equipment	Clinicians may prefer familiar equipment and be slow to adopt new technology.
Individuals and Stakeholders	Human oversight remains crucial despite technological advancements	Despite the advancement of technology, such as robots performing tasks like ventilation.

Category	Code	Description
Individuals and Stakeholders	Human-Machine Interaction Evolution in Healthcare	Observation on how human-machine interaction has evolved from being merely a tool to becoming an integral part of healthcare, especially during emergencies.
Individuals and Stakeholders	Development of negotiation and mediation skills for team harmony	Highlights the need for healthcare professionals to develop negotiation and mediation skills to resolve conflicts and ensure harmonious teamwork.
Individuals and Stakeholders	Emphasis on patient-centered care through PROM integration	Highlights the growing importance of incorporating patient perspectives into healthcare assessments.
Individuals and Stakeholders	Ease of use critical to clinical uptake	Notes that rehabilitation robots must be intuitive and user-friendly.
Individuals and Stakeholders	Telehealth and remote monitoring as a solution for wider access	Exploration of telehealth and remote monitoring technologies to extend healthcare access to patients in remote areas and reduce the need for in-person.
Individuals and Stakeholders	Deliberate talent acquisition surpasses reactive hiring	Emphasizing that building a successful team requires a proactive and strategic approach to talent acquisition, contrasting it with a reactive hiring process.
Individuals and Stakeholders	Data-driven risk management through connection building	Acknowledges the inherent risk in decision-making, in uncertain environments.
Individuals and Stakeholders	Lack of established trust criteria between stakeholders in AI	Notes a deficiency in established trust criteria among users, administrators, and developers regarding AI technologies.
Individuals and Stakeholders	Recognition of the potential for imposing solutions without user understanding	Acknowledges the risk of engineers imposing solutions without fully understanding user needs and challenges.
Individuals and Stakeholders	Initial excitement of staff for new technology implementation	Staff members express enthusiasm and curiosity towards the introduction of a new robot and technology within the healthcare setting.
Individuals and Stakeholders	Targeting stakeholder-reported issues fosters acceptance	The decision to apply the robot to a problem frequently voiced by staff and patients was crucial for gaining acceptance.
Individuals and Stakeholders	Initial excitement diminishes with prolonged exposure	Notes that initial enthusiasm and novelty surrounding the robot's presence gradually faded as staff became accustomed to its operation.
Individuals and Stakeholders	Reliability fosters research-hospital trust	The process of establishing trust with the hospital involved a phased approach, relying on consistently delivering successful experiments and demonstrating reliability.

Category	Code	Description
Individuals and Stakeholders	Minimizing disruption and perceived threat to existing workflows	A key factor in building trust was ensuring that the research activities did not disrupt existing hospital workflows or create a sense.
Individuals and Stakeholders	Generating value for staff as a trust-building strategy	Demonstrating that the research activities ultimately provide benefits for hospital staff was crucial for fostering trust.
Individuals and Stakeholders	Building trust through consistent delivery and positive outcomes	Understanding that ongoing support and the ability to push boundaries depend on consistently delivering on promises, generating positive press.
Individuals and Stakeholders	Integration of standard research methods for academic validation	Acknowledges the need to incorporate standard research methodologies, such as technology acceptance surveys, to ensure academic rigor and facilitate publication.
Individuals and Stakeholders	Staff experience as a crucial indicator of technology integration	Identifying whether the technology hinders staff or saves them time as a key metric for assessing its integration and usability.
Individuals and Stakeholders	Concern about clinician reliance and potential for automated approval	Highlights the risk of clinicians automatically approving AI-generated outputs, even with the intention of refinement.
Individuals and Stakeholders	Reliance on quantitative metrics alongside subjective clinical judgment	Acknowledges the existence of standard quantitative metrics for evaluating systems.
Individuals and Stakeholders	Clinical expertise crucial for identifying critical flaws	Highlights the essential role of clinical expertise in identifying critical flaws that quantitative metrics might overlook.
Individuals and Stakeholders	Importance of user research and problem validation through conversation	Emphasizes the necessity of engaging in thorough user research and problem validation through open-ended conversations, rather than presenting pre-conceived ideas.
Individuals and Stakeholders	Value of open-ended questioning over presenting product ideas	Advocating for a conversational approach to gathering feedback, where questions are prioritized over presenting product ideas.
Individuals and Stakeholders	Need for administrator buy-in before product development	Stressing the importance of securing administrator approval and understanding their budget priorities before initiating product development.
Individuals and Stakeholders	Importance of observing healthcare professionals' workflows	Suggesting the value of immersive observation of healthcare professionals' daily routines to gain a deeper understanding of their needs and challenges.
Individuals and Stakeholders	Navigating stakeholder engagement in software implementation	Highlights the challenges associated with managing numerous stakeholders during software deployment, within a hospital system.

Category	Code	Description
Individuals and Stakeholders	Need for clinical partnership for software validation	Emphasizes the necessity of collaborating with a hospital partner to validate software in a clinical setting.
Individuals and Stakeholders	Validation team assesses impact on patient outcomes	Emphasizes the validation team's responsibility to ensure the technology positively impacts patient care.
Individuals and Stakeholders	Primary engagement with clinical collaborators	Focus on the direct and consistent interaction with clinicians and the clinical group involved in the project.
Individuals and Stakeholders	Reliance on clinical collaborators for expertise and requirements	Describing a practice of direct communication with clinical collaborators to obtain necessary expertise and understand their specific needs.
Individuals and Stakeholders	Direct interaction primarily with clinical staff	Highlights that the primary point of contact and interaction is with clinical staff, rather than managers or other administrative personnel.
Individuals and Stakeholders	Clinician receptiveness to machine learning concepts	Notes that some clinicians demonstrate a greater openness and understanding of machine learning principles, allowing for more technical discussions about system performance.
Individuals and Stakeholders	Visual demonstration enhances clinician trust and acceptance	Understanding that clinicians primarily rely on visual representations of data and system outputs to validate performance and build confidence.
Individuals and Stakeholders	Optimistic outlook on the future of healthcare technology	Expresses a positive belief in the direction of healthcare technology, highlighting a desire for progress and improvement in the field.
Individuals and Stakeholders	Communication challenges in translating technical concepts	Describing difficulties in conveying technical information to non-technical stakeholders, leading to misunderstandings and delays in project implementation.
Individuals and Stakeholders	Misconceptions about the capabilities of artificial intelligence	Addressing the common misunderstanding that AI can solve any problem, emphasizing the reliance on data quality and completeness for effective AI implementation.
Individuals and Stakeholders	Desire for multidisciplinary collaboration in healthcare technology	Expresses a positive view on the increasing trend of multidisciplinary teams working together in healthcare technology.
Individuals and Stakeholders	Varied clinician experience impacts system utilization	Notes that clinicians with varying levels of experience may utilize the system differently.
Individuals and Stakeholders	User interaction and system adoption are key performance indicators	Emphasizes the importance of observing and understanding how users interact with the decision support system.
Individuals and Stakeholders	Recognizing the need for collaborative effort for progress	Emphasizes the importance of collective action and bringing various stakeholders together to achieve meaningful progress in healthcare technology.

Category	Code	Description
Individuals and Stakeholders	Initiative in bridging interdisciplinary gaps	Shows a proactive approach to fostering connections between different disciplines within the organization.
Individuals and Stakeholders	Acknowledging limitations and focusing on issue identification	Highlights the ambitious nature of the project and the constraints of the timeframe.
Individuals and Stakeholders	US clinicians emphasize team dependence for care	Notes that US clinicians, specialists, frequently highlight their dependence on the broader medical team for effective care delivery.
Individuals and Stakeholders	Projection of perceived persecution onto patients	Description of how clinicians' feelings of persecution are projected onto patients.
Individuals and Stakeholders	Medical records as contested and biased data sources	Medical records are inherently subjective and prone to bias, reflecting the perceptions and interpretations of various healthcare providers.
Individuals and Stakeholders	Vulnerability as a cornerstone of trust in healthcare	Trust in healthcare hinges on mutual vulnerability, where both parties have something to lose, creating a context for genuine connection and care.
Individuals and Stakeholders	Defining care as temporary support for individual capacity	Care is fundamentally about providing temporary support to individuals when they are unable to fulfill their own needs.
Individuals and Stakeholders	Shifting power dynamics in patient-clinician decision-making	The Consultant acknowledges the increasing emphasis on shared decision-making between clinicians and patients.
Individuals and Stakeholders	Cognitive limitations necessitate technological support in medicine	The Consultant emphasizes that the sheer volume of medical knowledge now exceeds any single clinician's capacity.
Individuals and Stakeholders	Erosion of trust impacting professional commitment	Theory that a breakdown in trust between clinical professionals and society is contributing to the observed disengagement.
Legal Responsibilities and Liability Risks	Ethical concerns surrounding the 'black box' nature of AI	Highlights ethical challenges posed by AI systems lacking transparency and explainability.
Legal Responsibilities and Liability Risks	Need for human override function in AI decision-making	Highlights the necessity for a human override function in AI systems, in healthcare, to ensure patient safety and accountability.
Legal Responsibilities and Liability Risks	Importance of traceability and problem resolution in AI systems	Emphasizes the need for AI systems to be 'open' to allow for traceability and problem resolution in case of incidents.
Legal Responsibilities and Liability Risks	Post-market responsibilities shift to corporate structures	Acknowledges that after acquisition, the responsibility for ongoing post-market surveillance typically falls to large companies with dedicated departments.

Category	Code	Description
Legal Responsibilities and Liability Risks	Focus on regulatory approval as a liability mitigation strategy	Notes that regulatory approval is being prioritized as a means of minimizing liability.
Legal Responsibilities and Liability Risks	Physician liability concerns hindering AI acceptance	Highlights physician reluctance to adopt AI due to concerns about liability for decisions made with AI assistance.
Legal Responsibilities and Liability Risks	Prioritizing patient safety and ethical considerations in technology development	Highlights the importance of avoiding experimentation on patients during the prototyping phase and ensuring that technology is thoroughly tested and refined before.
Legal Responsibilities and Liability Risks	Acceptance of inevitable errors in technological development	Acknowledges that mistakes are an inherent part of the technological development process and that initial deployments should prioritize safety through controlled environments.
Organisational Structures and Processes	Lack of constraint in procurement decisions	Perception that procurement decisions are not subject to sufficient constraints or oversight.
Organisational Structures and Processes	Administrative disconnect from frontline clinical needs	Reflects on the difficulty in communicating the value of new technologies to administrative counterparts.
Organisational Structures and Processes	Pandemic Impact on Health Systems and AI Utilization	Reflects on impact pandemics have on training health systems, highlighting a missed opportunity for AI in disease modeling and pandemic management.
Organisational Structures and Processes	Pandemic as a catalyst for technology deployment	The pandemic highlighted deficiencies and created an urgent need to adopt new technologies, including AI.
Organisational Structures and Processes	Formal processes required for technology integration	Highlights the need for formal procedures and policies to govern the introduction of new technologies into clinical settings.
Organisational Structures and Processes	Framework for medical device success involves balancing four key performance axes	Explanation of a framework for medical device success, emphasizing the need for balanced progress across clinical, business, technical, and regulatory performance axes.
Organisational Structures and Processes	Compliance efforts divert resources from product safety and quality	Notes that excessive focus on regulatory compliance diverts resources and time away from core activities like product safety and quality improvement.
Organisational Structures and Processes	Disruption of engineering continuity after acquisition	Reflects on the negative consequences of corporate acquisition.
Organisational Structures and Processes	Slow decision-making due to risk aversion in AI adoption	Reflects on the slow pace of AI integration in healthcare, attributed to a risk-averse decision-making process.

Category	**Code**	**Description**
Organisational Structures and Processes	Hospital willingness to experiment with new technologies	Highlights the positive attribute of the hospital's openness to experimenting with new technologies.
Organisational Structures and Processes	Project disruption due to COVID	Notes that the project's progress was significantly hampered by the COVID-19 pandemic, leading to a loss of momentum and halting further development.
Organisational Structures and Processes	Misalignment of robotic innovation with operational needs	Notes that robotic initiatives are often driven by marketing or a desire for innovation, rather than operational considerations.
Organisational Structures and Processes	Need for cultural and team ownership shift for robotic implementation	Recognizes the necessity for a cultural and team ownership shift to successfully implement robotics in a production setting.
Organisational Structures and Processes	Applying accumulated know-how to new contexts	Notes the team's progression beyond the initial project, with a focus on leveraging acquired knowledge and expertise in new areas.
Organisational Structures and Processes	Demonstrating value to hospital management and staff	Need to show clear benefits for patients and operations to maintain leadership and staff buy-in.
Organisational Structures and Processes	Media visibility as a lever for expansion	Positive media coverage can help attract funding and support, enabling program expansion.
Organisational Structures and Processes	Recognition of hospital-specific challenges in software deployment	Acknowledges the unique challenges associated with deploying software within a hospital environment, suggesting a need for specialized knowledge and adaptation.
Organisational Structures and Processes	Balancing industry research with academic rigor	The team navigates the intersection of industry-focused research and academic principles.
Organisational Structures and Processes	Need for increased collaboration between developers and healthcare professionals	Recognizes the necessity for stronger partnerships between developers, clinicians, and managers to ensure effective implementation of healthcare technologies.
Organisational Structures and Processes	Desire for collaborative decision-making across disciplines	Expression of a desire for a more collaborative approach to decision-making, moving away from a traditional chain-of-command structure.
Organisational Structures and Processes	Lack of established framework hinders multidisciplinary collaboration	Highlights the difficulty in conducting collaborative work across disciplines due to the absence of a structured framework.

Category	Code	Description
Organisational Structures and Processes	Acknowledging limitations in implementation due to systemic factors	Reflects on the difficulty of seeing healthcare technology implementations due to broader systemic challenges and barriers.
Organisational Structures and Processes	Consistent themes across UK and US healthcare systems	Despite differences in financial and power structures.
Organisational Structures and Processes	Siloed organizational structures impact care delivery	Description of UK healthcare teams as often being siloed organizational units with specific legal responsibilities and performance indicators.
Organisational Structures and Processes	Integrated care boards foster emergent networks	Discusses the reorganization of UK healthcare into integrated care boards, bringing together NHS and social services.
Organisational Structures and Processes	Clinician burnout and systemic crisis across healthcare systems	Describing a pervasive state of crisis within both healthcare systems, characterized by clinicians reaching a breaking point due to intense pressure.
Organisational Structures and Processes	Organizational units exhibit regressed emotional responses	Observing that organizational units within the healthcare system are operating in a psychologically regressed state, characterized by feelings of victimization, abandonment.
Organisational Structures and Processes	Traumatization hinders productive team functioning	Highlights how the pervasive sense of trauma within healthcare organizations significantly impedes productive teamwork, communication, and collaboration.
Organisational Structures and Processes	Clinician blame directed towards insurance restrictions	Notes that clinicians often attribute limitations in their practice to restrictions imposed by insurance companies.
Organisational Structures and Processes	Similar underlying dynamics across healthcare systems	Acknowledges that despite differing perceptions and ascribed incentives.
Organisational Structures and Processes	Team agency and autonomy in care provision	The consultant reflects on the potential for a team to provide care, emphasizing the importance of agency, freedom.
Organisational Structures and Processes	Distinction between team dynamics and systemic control	The consultant highlights a conceptual difference between a team, defined by its internal relationships and autonomy, and a system.
Participant Professional Background	Clinical experience across diverse intensive care settings	Shows a broad range of experience in ICU medicine, spanning multiple hospitals, specialties, and roles.
Participant Professional Background	Managing an extensive rehabilitation service portfolio	Reflects on the breadth and complexity of the current acting management role, encompassing multiple rehabilitation services and a large multidisciplinary team.

Category	Code	Description
Participant Professional Background	Engineering background and regulatory expertise	Highlights the participant's foundation as an engineer and how this experience shapes their current focus on regulatory aspects within the medical device.
Participant Professional Background	Freelance consulting supports early-stage medical device startups	Describing the participant's current role as a freelance consultant, specifically focusing on assisting early-stage medical device startups with team design, regulatory strategy.
Participant Professional Background	Bridging the gap between technical expertise and regulatory understanding	Description of the role in assisting developers and entrepreneurs in comprehending the complexities of regulatory compliance.
Participant Professional Background	Broad expertise across diverse medical technology domains	Reflects on possessing a wide range of experience across various medical technology areas, including those without ICT or power.
Participant Professional Background	Familiarity with collaborative research in healthcare robotics	Reflects on prior experience collaborating on research projects involving social robots within a healthcare setting.
Participant Professional Background	Transition from clinical practice to startup creation	Reflects on shifting from a stable role as a medical physicist in a radiotherapy clinic to the uncertainty of founding a startup.
Participant Professional Background	Pivot to AI consulting to leverage expertise and generate income	Describing the strategic shift from medical device development to AI consulting as a means of utilizing their skills and experience while addressing.
Participant Professional Background	Background in computer science and affective computing	Describes the foundational academic background in computer science, specifically highlighting experience with affective computing and emotion recognition.
Participant Professional Background	Application of machine learning to physiological signals for clinical decision support	Details the current work applying machine learning techniques to physiological signals, such as vital signs, to support clinical decision-making.
Participant Professional Background	Focus on early disease detection and risk stratification	Emphasizes the goal of using machine learning to detect diseases earlier and to stratify patient risk.
Participant Professional Background	Transition from technology development to qualitative research	Reflecting on a career shift from direct involvement in technology and product development to a focus on qualitative research involving clinicians, patients.
Participant Professional Background	Focus on understanding emotional and contextual factors	Describing a current focus on understanding the emotional drivers, pressures, and contextual factors influencing clinicians, patients, and healthcare system owners.

Category	Code	Description
Participant Professional Background	Providing a broad overview of healthcare perspectives	Positioning themselves as someone who offers a comprehensive understanding of the pressures and emotional drivers within the healthcare landscape.
Participant Professional Background	Working with diverse stakeholders to influence behaviour	Describes working with pharmaceutical companies, payers, and public health bodies to influence clinician and patient behaviour.
Participant Professional Background	Deep understanding of systems and decision-making	Focuses on the need for in-depth investigation into how decisions are made within healthcare systems, including understanding the perspectives, tensions.
Participant Professional Background	Recommendations span multiple intervention points	Highlights the broad range of potential intervention points, including communications, systems, policy, and co-production/design.
Physical and Contextual Environment	Intensive care unit design prioritizes technology over patient visibility	Reflects on the shift in ICU design, where the focus has moved from patient-centered care to accommodating a multitude of technological devices.
Physical and Contextual Environment	Increased reliance on technology necessitates extensive infrastructure	Notes infrastructural changes required to support the proliferation of medical devices in ICU units.
Physical and Contextual Environment	Technological proliferation creates a human-machine imbalance	Notes that the number of machines now exceeds the number of human caregivers present around ICU patients.
Physical and Contextual Environment	Adherence to hospital hygiene standards	Emphasizes the necessity for equipment to meet stringent hospital standards for infection control.
Physical and Contextual Environment	Physical infrastructure challenges in rehab settings	Discusses the practical difficulties in integrating new technology, specifically the need to remove existing equipment to accommodate the robot.
Physical and Contextual Environment	Prioritizing patient safety restricts robot mobility	Explanation that concerns about obstructing patient care and emergency situations prevented unrestricted robot movement.
Physical and Contextual Environment	Designated robot-safe zones represent a future navigation solution	Suggestion of creating designated areas for robot operation as a potential solution to navigation limitations.
Professional Roles, Scopes, and Guidelines	Human roles will evolve, not disappear, with AI integration	The participant envisions a future where embodied AI and robots could provide healthcare in extraplanetary environments.
Professional Roles, Scopes, and Guidelines	AI's potential in predictive healthcare beyond intensive care	The professional anticipates a transformative role for AI systems.

Category	**Code**	**Description**
Professional Roles, Scopes, and Guidelines	Complementing human traits like empathy with computational intelligence	The professional reflects on the importance of integrating AI systems with inherently human qualities such as empathy.
Professional Roles, Scopes, and Guidelines	Emphasis on teamwork and collaboration in professional training	Description of the increasing focus on teamwork and collaboration within healthcare professional training programs.
Professional Roles, Scopes, and Guidelines	Safety as a procurement criterion for robotic systems	Notes that safety mechanisms are a critical factor in the selection and procurement of rehabilitation robots.
Professional Roles, Scopes, and Guidelines	Evidence of prior clinical use informs selection	Emphasizes choosing robots that have been successfully used in comparable hospital settings with similar patient populations.
Professional Roles, Scopes, and Guidelines	Training and technical support as enabling factors	Identification of ongoing maintenance and accessible training as essential for successful robot adoption.
Professional Roles, Scopes, and Guidelines	Champions developing in-house expertise for new technologies	Implementation of an internal training program to build expertise and reduce reliance on external support for complex technologies.
Professional Roles, Scopes, and Guidelines	Training champions to cascade knowledge to junior staff	Highlights the need to identify and train senior clinicians who can then train other staff members on the use of robots.
Professional Roles, Scopes, and Guidelines	Lack of evidence-based guidelines for robotic rehabilitation dosage	Highlights a gap in knowledge regarding optimal treatment parameters for robotic rehabilitation, including frequency, intensity, and duration of therapy.
Professional Roles, Scopes, and Guidelines	Adherence to industry consensus and 'reasonably achievable state of art'	Discusses the importance of aligning doctor selection with established industry practices and the 'reasonably achievable state of art'.
Professional Roles, Scopes, and Guidelines	Recognition of limitations of accuracy as a sole evaluation metric	Expresses the understanding that accuracy alone is insufficient for comprehensively evaluating a model's performance, in clinical settings.
Professional Roles, Scopes, and Guidelines	Recognition of the need for problem-specific evaluation metrics	No single metric works for everything; evaluation should match the specific task and context.
Professional Roles, Scopes, and Guidelines	Understanding the trade-offs between minimizing false positives and false negatives	Acknowledges the inherent trade-offs involved in optimizing model performance.
Professional Roles, Scopes, and Guidelines	Reliance on clinical expertise for metric selection	Acknowledges the necessity of incorporating clinical professionals' knowledge when choosing evaluation metrics, recognizing that not all clinicians possess statistical understanding.

Category	Code	Description
Professional Roles, Scopes, and Guidelines	Bridging the gap between statistical methods and clinical understanding	Recognizes the challenge of explaining statistical methods to clinicians who may lack statistical background.
Professional Roles, Scopes, and Guidelines	Explainability is contingent on project scope and client needs	Reflects on the selective application of explainability features in healthcare technology projects.
Professional Roles, Scopes, and Guidelines	Recognition of the need for systems engineers and architects	Acknowledges the value of systems engineers and architects in the project.
Professional Roles, Scopes, and Guidelines	Clinical decision support systems should augment, not replace, clinicians	Understanding that the purpose of a clinical decision support system is to assist clinicians in their decision-making process.
Professional Roles, Scopes, and Guidelines	Predictive tools supporting complex clinician communication	The Consultant suggests predictive tools can help clinicians navigate difficult conversations and consider various outcomes in a safe environment.
Professional Roles, Scopes, and Guidelines	Clinician utilizing AI for conversation practice and preparation	Notes clinicians using Chat-GPT to rehearse difficult patient conversations, focusing on understanding potential reactions and improving shared decision-making skills.
Professional Roles, Scopes, and Guidelines	Evidence-based decision making requires relating statistics to individual choices	Acknowledges the difficulty of translating population statistics into individual patient choices, regardless of AI involvement.
Regulatory Frameworks and Standards	Regulatory and legal frameworks cause increased demand for intensive care	Discusses how regulatory frameworks and the medical-legal environment contribute to increased workload through the need for documentation and detailed records of patient.
Regulatory Frameworks and Standards	Regulatory approval as a procurement requirement	Requirement that robotic rehabilitation devices have Therapeutic Goods Administration approval,.
Regulatory Frameworks and Standards	Disconnect between regulatory systems and engineering logic	Reflects on the disconnect between the rational, system-oriented mindset of developers and the often-illogical and bureaucratic nature of regulatory compliance.
Regulatory Frameworks and Standards	Demonstrating technological effectiveness requires validation records and research publications	Explanation of the need to provide evidence of technological effectiveness through validation records and research publications.
Regulatory Frameworks and Standards	Regulatory ambiguity hinders innovation and product evolution	Discusses the current regulatory landscape's inability to accommodate evolving technologies, AI-enabled systems.

Category	Code	Description
Regulatory Frameworks and Standards	Pilot programs offer potential for adaptive regulation	Exploration of the FDA's pilot program as a potential solution for regulating adaptive technologies.
Regulatory Frameworks and Standards	Regulatory delays create market distortions and disadvantage compliant companies	Reflects on the negative consequences of prolonged regulatory delays, including market distortions and unfair advantages for non-compliant companies.
Regulatory Frameworks and Standards	Quality definition disconnected from practical implementation	Reflects on the disconnect between the theoretical definition of quality and how it's actually practiced within the industry.
Regulatory Frameworks and Standards	Quality management transformed into a regulatory compliance exercise	Notes that quality management, originally an industry-led initiative, has become a bureaucratic 'tick-box' exercise driven by regulatory requirements.
Regulatory Frameworks and Standards	Regulatory limits discourage high-risk, high-outcome innovation	Reflects on how bureaucratic regulatory limits discourage companies from pursuing high-risk, high-outcome innovations.
Regulatory Frameworks and Standards	Regulatory systems often allow large companies to avoid real consequences	Notes that adhering to regulations is expected and doesn't provide a competitive advantage.
Regulatory Frameworks and Standards	Design controls are overly prescriptive and inflexible	Critiques design controls as being too rigid and formulaic, hindering innovation and failing to truly reflect the complexities of product development.
Regulatory Frameworks and Standards	Medical device regulation divides into pre-market and post-market phases	
Regulatory Frameworks and Standards	Regulatory compliance prioritized over engineering innovation	Notes that post-market regulatory compliance in larger corporations often prioritizes maintaining compliance at the lowest cost.
Regulatory Frameworks and Standards	Mutual Recognition Agreements for international market access between TGA and Europe	Description of a past system where Mutual Recognition Agreements between the TGA and Europe streamlined product approvals.
Regulatory Frameworks and Standards	Regulatory ambiguity creates uncertainty for manufacturers	Reflects on the ongoing challenges posed by ambiguous regulatory guidelines for software and apps considered medical devices.
Regulatory Frameworks and Standards	Regulatory framework misalignment with AI adoption challenges	Critiques the current regulatory framework, suggesting it is not addressing the specific challenges associated with AI adoption in healthcare.

Category	**Code**	**Description**
Regulatory Frameworks and Standards	Regulatory limitations preventing AI autonomy in healthcare	Acknowledges that current regulations prevent AI from assuming responsibility or autonomy in healthcare settings.
Regulatory Frameworks and Standards	Strategic avoidance of regulated applications	The participant and their team chose an unregulated application to reduce compliance requirements and speed up the research process.
Regulatory Frameworks and Standards	Navigating unfamiliar ethical review processes	Reflects on the challenges of obtaining ethical approval for novel technologies.
Regulatory Frameworks and Standards	Educating ethics committees about emerging technologies	Discusses the necessity to explain the functionality, risks, and benefits of robotics to ethics committees lacking prior experience with such technologies.
Regulatory Frameworks and Standards	Avoidance of medical device development due to regulatory hurdles	Expresses a conscious decision to avoid further involvement in medical device development due to the lengthy and complex regulatory approval processes.
Regulatory Frameworks and Standards	Regulatory hurdles and classification challenges due to AI complexity	Encountering difficulties in navigating regulatory frameworks, specifically concerning the classification of AI-powered medical devices.
Regulatory Frameworks and Standards	Standardized validation using metrics and clinical validation	Validation blends quantitative metrics with clinician review to confirm model outputs match clinical expectations.
Regulatory Frameworks and Standards	Recognition of external resources for regulatory guidance	Acknowledges the existence of external resources, such as openregulatory.com, that provide templates and guidance for regulatory compliance.
Regulatory Frameworks and Standards	Understanding of IEC 62366 standard for medical device usability	Shows understanding of the IEC 62366 standard, which focuses on the usability of medical device software.
Regulatory Frameworks and Standards	Regulatory oversight focuses on company procedures, not doctor selection	Explanation that regulatory agencies do not dictate the selection of doctors for studies.
Regulatory Frameworks and Standards	Navigating regulatory requirements for healthcare technology prototypes	Discusses the necessity to adhere to clinical trial notification processes when healthcare technology prototypes interact with patients or enter patient workflows.
Regulatory Frameworks and Standards	Strategic avoidance of medical device classification during prototyping	Emphasizes the strategic advantage of keeping prototypes outside the classification of medical devices, during early development stages.
Regulatory Frameworks and Standards	Prototypes require extensive ethical review and system integration	Understanding that even promising prototypes and models necessitate thorough ethical review processes and complex integration into existing healthcare systems.

Category	Code	Description
Regulatory Frameworks and Standards	Awareness of regulatory hurdles impacting technology deployment	Notes that regulatory processes introduce delays and complexities in the deployment of new technologies, regardless of the speed of model development.
Societal Norms and Cultural Expectations	Societal expectations drive increased demand for intensive care	Reflects on how rising societal expectations for healthcare outcomes contribute to a higher demand for ICU services.
Societal Norms and Cultural Expectations	Resistance to adopting newer technologies in healthcare	Highlights resistance to adopting newer technologies, even when they are demonstrably better than older ones.
Societal Norms and Cultural Expectations	Patient Reported Outcome Measures bridge the gap between clinical and patient experience	Highlights the importance of understanding patient perspectives and aligning interventions with their individual goals and perceived recovery.
Societal Norms and Cultural Expectations	Communication barriers in regulatory compliance	Notes a reluctance among those being guided through regulatory processes to question the rationale behind requirements.
Societal Norms and Cultural Expectations	Template-driven compliance fosters superficial quality	Concern that the prevalence of template-based consulting creates a culture of 'checking boxes' rather than genuinely pursuing quality.
Societal Norms and Cultural Expectations	Proactive robotic research driven by engineering goals rather than user need	Reflects on the tendency for engineers to initiate technology adoption based on their own vision, rather than responding to user demand.
Societal Norms and Cultural Expectations	Shift from novelty to functional utility in user interaction	Notes a change in user perception of robots.
Societal Norms and Cultural Expectations	Functional inquiry dominates user engagement in healthcare settings	Notes that user interactions with robots in a hospital environment are primarily focused on practical assistance and information retrieval.
Societal Norms and Cultural Expectations	Humanoid robot seen as functional tool	Notes that in a healthcare setting, individuals perceive humanoid robots as tools rather than entities with human-like qualities.
Societal Norms and Cultural Expectations	Contextual factors influence robot perception	Notes that the environment and the specific task influence how individuals perceive robots.
Societal Norms and Cultural Expectations	Decreased novelty of robots due to increased exposure	Notes that the novelty associated with robots has diminished over time due to increased exposure and familiarity.
Societal Norms and Cultural Expectations	Historical shift in robot familiarity and acceptance	Highlights a historical change in how robots are perceived, noting that earlier years saw less familiarity.

Category	Code	Description
Societal Norms and Cultural Expectations	Continued passion for AI's potential in healthcare	Maintaining a strong belief in the transformative power of AI to improve healthcare outcomes, despite past setbacks.
Societal Norms and Cultural Expectations	Excitement and apprehension regarding the future of AI	Expresses a dualistic perspective on the future of AI.
Societal Norms and Cultural Expectations	Urgency to redirect AI development efforts	A strong sense of urgency and a call to action for AI professionals to shift their focus and resources towards ensuring human.
Societal Norms and Cultural Expectations	Differing perceptions of systemic intent between UK and US	Contrast between the UK and US healthcare systems regarding perceived intent.
Societal Norms and Cultural Expectations	Shifting paradigms challenge communication and collaboration	The current era is marked by individuals living within distinct 'paradigmatic realities,' making communication and collaboration difficult.
Societal Norms and Cultural Expectations	Individualism versus collective responsibility in healthcare access	A tension exists between the belief in self-reliance and the expectation of collective responsibility for healthcare.
Societal Norms and Cultural Expectations	Systems versus individual relationships in delivering care	Questioning whether large systems like the NHS can truly provide personalized care, suggesting that care fundamentally happens within individual relationships between people.
Societal Norms and Cultural Expectations	Exploring vulnerability and agency in human-technology interactions	Considering whether a caring relationship can exist between a technological actor and a vulnerable human.
Societal Norms and Cultural Expectations	Shift from personalized care to system-driven objectives	The consultant describes a transition where care becomes depersonalized as objectives are imposed from a higher level.
Technological Ecosystem and Interoperability	Consumer tech outpaces hospital technology	Contrast between the availability of wearable technology for patients outside of the hospital setting and the limitations on technology available to patients.
Technological Ecosystem and Interoperability	Past negative consequences of insufficiently transparent AI implementation	Reflects on a previous incident where a pump with limited transparency led to negative consequences and required a return to previous methods.
Technological Ecosystem and Interoperability	AI integration requires adaptation of existing IT infrastructure	Notes that the implementation of AI-powered medical devices necessitates upgrades and improvements to current IT systems.
Technological Ecosystem and Interoperability	Collaboration with researchers fosters technological advancement	Acknowledges the ongoing collaboration with researchers at UC, robotic engineers, to integrate prototype devices and enhance existing technologies.

Category	**Code**	**Description**
Technological Ecosystem and Interoperability	Gap between research and production readiness for robotics	Identifying a substantial difference in effort required to transition from a supervised research setting to a production-ready environment for robotics.
Technological Ecosystem and Interoperability	Transferability of technological expertise to healthcare	Notes that technologies developed for a specific project possess potential applicability across diverse fields, including healthcare.
Technological Ecosystem and Interoperability	Recognition of limitations in research for practical application	Acknowledges that research projects often lack the scope to account for factors crucial for real-world implementation and adoption of technologies.
Technological Ecosystem and Interoperability	Desire for a systems approach for enhanced safety	Expresses a hope that OpenSaMD would adopt the STPA approach, recognizing its value in creating more robust and safe systems.
Technological Ecosystem and Interoperability	Current validation practices focus on component-level testing	Description of the current validation process, which involves unit testing and comparison against ground truths using standardized machine learning data splits.
Technological Ecosystem and Interoperability	Standardized metrics for geometric shape comparison	Describing the use of specific metrics like surface distance and DICE score for comparing geometric shapes in 3D space.
Technological Ecosystem and Interoperability	Recognizing the potential for software engineer ideas to fail without industry collaboration	Acknowledges the risk of software engineers developing solutions that are not aligned with industry needs.
Technological Ecosystem and Interoperability	Importance of traceability in software deployment	Highlights the concept of traceability as a crucial element in software deployment, ensuring accountability and facilitating iterative improvements based on feedback.
Technological Ecosystem and Interoperability	Minimal UI promotes adoption	Advocating for a ’zero-click’ approach to technology implementation, minimizing the need for user interaction and integrating seamlessly with existing systems.
Technological Ecosystem and Interoperability	Navigating enterprise IT security protocols as a technical challenge	Reflects on the difficulties encountered when integrating with existing IT security infrastructure.
Technological Ecosystem and Interoperability	Leveraging prior research to inform development pathways	The team integrates existing research and literature to guide the development process.
Technological Ecosystem and Interoperability	Complex projects involving multiple data types necessitate explainability features	Notes that larger, more complex projects utilizing diverse data sources require the incorporation of explainability features.
Technological Ecosystem and Interoperability	Importance of data quality and completeness for AI development	Highlights the critical role of comprehensive and accurate data in enabling successful AI development and implementation.

Category	Code	Description
Technological Ecosystem and Interoperability	Importance of data infrastructure teams understanding model building processes	Emphasizes the need for data infrastructure teams to possess an understanding of the model-building processes.
Technological Ecosystem and Interoperability	Infrastructure support is essential for system deployment	Acknowledges that successful system deployment requires robust infrastructure support, including data management and integration.
Technological Ecosystem and Interoperability	Developer frustration with data-only project handoffs	Expresses a challenge faced by developers who are simply given data and expected to build models without understanding the broader clinical context.
Technological Ecosystem and Interoperability	Need for developer understanding of deployment context	Highlights the importance of developers having a clear understanding of how a model will be deployed and integrated into a hospital's workflow.
Technological Ecosystem and Interoperability	Model performance is a baseline, not a primary evaluation factor	Acknowledges that model performance is important but secondary to user interaction and system adoption.
Technological Ecosystem and Interoperability	Systemic barriers to inter-organizational communication and collaboration	Challenges in communication and collaboration exist not only within clinical systems but also between healthcare, social care, and welfare systems.
Technological Ecosystem and Interoperability	Increased system interconnectedness reveals capability gaps	Notes that as more parts of the healthcare system communicate, a greater awareness emerges of missing skills, resources, and capabilities.
Technologies, Devices, and Digital Systems	Improved patient outcomes because of technology	Reflects on the necessity of technology in ICU, emphasizing that its adoption is driven by demonstrable improvements in patient health outcomes.
Technologies, Devices, and Digital Systems	Machines provide objective and continuous patient monitoring	Highlights the value of machines in providing objective, real-time, and continuous data for patient monitoring.
Technologies, Devices, and Digital Systems	Technology enables precise and accurate care beyond human capabilities	Acknowledges the capability of machines to administer fluids with a level of precision and accuracy that is beyond human capabilities.
Technologies, Devices, and Digital Systems	Lack of user experience design contributes to technical difficulties	Notes that a lack of user-centered design in medical equipment contributes to technical difficulties and increases the time spent troubleshooting.
Technologies, Devices, and Digital Systems	Newer machines and devices are less user friendly	Expresses a preference for older ventilator designs, specifically mentioning the Puritan Bennet 840, due to its capacitive multi-touch screen and simple.
Technologies, Devices, and Digital Systems	Disappointment with current user interface design in new devices	Expresses disappointment with the cluttered and less well-engineered user interfaces of newer ventilators, despite their reduced size.

Category	Code	Description
Technologies, Devices, and Digital Systems	Recognition of a design flaw in recent ventilator development	Acknowledges a perceived design flaw in the recent development of ventilators.
Technologies, Devices, and Digital Systems	Technological advancements shift from iteration to transformative insight	Reflects on how new technologies, those incorporating AI, represent a fundamental shift from incremental improvements to providing actionable insights.
Technologies, Devices, and Digital Systems	Transition from discrete data to actionable insight in patient monitoring	Discusses the need for technology to move beyond simply collecting data to providing clinicians with clear.
Technologies, Devices, and Digital Systems	AI as a solution to insight overload and care augmentation	Highlights the potential for AI to address the challenge of 'insight overload' resulting from advanced technologies.
Technologies, Devices, and Digital Systems	Challenges of AI implementation in non-linear specialties like intensive care	Acknowledges that ICU, unlike aviation, presents non-linear challenges for AI implementation.
Technologies, Devices, and Digital Systems	User experience limitations of current computerized health information systems	Critiques the current state of computerized health information systems, describing them as fragmented, poorly designed, and reminiscent of outdated software.
Technologies, Devices, and Digital Systems	Time spent troubleshooting and rebooting outdated health information systems	Describes time wasted by healthcare professionals due to the frequent breakdowns and need for rebooting of current computerized health information systems.
Technologies, Devices, and Digital Systems	Technology can reduce medication errors through enhanced checks	Notes that technology, e-prescription systems, can reduce medication errors by improving legibility, enabling remote pharmacy verification, and facilitating allergy checks.
Technologies, Devices, and Digital Systems	Acknowledging human contribution to errors	Acknowledges that implementing technology may lead to a trade-off between reducing errors and maintaining efficiency.
Technologies, Devices, and Digital Systems	AI-powered ventilators demonstrate significant positive impact on intensive care	Reflects on the transformative potential of AI-powered ventilators.
Technologies, Devices, and Digital Systems	AI will augment intensive care just like it did in radiology.	The professional discusses the role of AI systems like Aidoc and Everlight in assisting with diagnostic processes.
Technologies, Devices, and Digital Systems	AI systems evolving from tools to companions	The healthcare professional describes a shift in perception of AI systems, us2.ai.

Category	Code	Description
Technologies, Devices, and Digital Systems	AI as a bridge for applying healthcare expertise outside traditional settings	The professional envisions AI systems as a means to extend their knowledge and experience in managing critically ill patients to broader applications.
Technologies, Devices, and Digital Systems	AI's role in enhancing healthcare efficiency and decision-making	AI systems, including robotics and decision-making tools.
Technologies, Devices, and Digital Systems	AI systems as a positive outcome of pandemic challenges	The development and deployment of AI systems were significantly propelled by the pandemic.
Technologies, Devices, and Digital Systems	Evolution of assistive tools in rehabilitation	Highlights overhead hoists as a crucial safety measure in inpatient rehabilitation.
Technologies, Devices, and Digital Systems	Harness-supported treadmills facilitate weight-bearing practice	Description of harness-supported treadmills as a tool to assist patients with limited weight-bearing capacity.
Technologies, Devices, and Digital Systems	SAEBO devices enhance upper limb rehabilitation motivation	Highlights SAEBO devices as a motivational tool for upper limb rehabilitation, utilizing gamification to encourage patient engagement and practice.
Technologies, Devices, and Digital Systems	Integration of accessible gaming technology for rehabilitation	Utilization of a Wii console and its balance board as a rehabilitation tool.
Technologies, Devices, and Digital Systems	Robotic devices improve patient access to rehabilitation	Highlights the potential for robotic devices to enable patients to engage in longer rehabilitation sessions, leading to increased repetitions and improved outcomes.
Technologies, Devices, and Digital Systems	Robotic intervention improves independent mobility post-stroke	Notes that robotic intervention doubles the likelihood of patients regaining independent walking ability after experiencing a stroke.
Technologies, Devices, and Digital Systems	Adaptive assistance tailored to patient recovery	Preference for robots with active-assisted functionality that adjusts the level of support based on a patient's motor progress.
Technologies, Devices, and Digital Systems	Adaptive robotic assistance to encourage patient effort	Desire for robotic systems that can dynamically adjust the level of assistance provided.
Technologies, Devices, and Digital Systems	Importance of user-friendly robotic technology for clinical adoption	Highlights the critical need for robotic systems to be intuitive and easy to use for clinicians, those without technical expertise.
Technologies, Devices, and Digital Systems	Adaptability to diverse patient body types	Highlights the need for equipment to accommodate a wide range of patient sizes and shapes, addressing the increasing prevalence of bariatric patients.

Category	**Code**	**Description**
Technologies, Devices, and Digital Systems	Importance of fine motor control in upper rehabilitation	Highlights the critical role of fine motor skills and graduated movements in upper limb rehabilitation.
Technologies, Devices, and Digital Systems	Exploring robotic technology for patient interaction	Discusses a study involving the implementation of a Pepper robot to interact with patients experiencing low-level dementia on an older person's ward.
Technologies, Devices, and Digital Systems	Robot technology will improve with use	Anticipation that the performance of rehabilitation technologies will improve with increased usage and operational experience, leading to better patient results.
Technologies, Devices, and Digital Systems	Desire for smaller, user-friendly rehabilitation robots	Focus on developing smaller, more user-friendly rehabilitation robots that can be easily deployed in patients' homes.
Technologies, Devices, and Digital Systems	Disparity between industrial robotics and healthcare application	Highlights a difference in functionality and reliability between robots used in controlled industrial settings and those intended for use in dynamic healthcare.
Technologies, Devices, and Digital Systems	Frustration with lack of transparency in medical device development	Expresses disappointment and challenge due to the absence of openly available information and established practices in the medical device industry.
Technologies, Devices, and Digital Systems	Prioritizing core functionality over unnecessary features	Advocating for a minimalist approach to software development, prioritizing core functionality and avoiding unnecessary features to ensure a streamlined and efficient product.
Technologies, Devices, and Digital Systems	Understanding the impact of false positives and false negatives	Demonstrating awareness of the consequences of both false positives and false negatives in clinical model deployment.
Technologies, Devices, and Digital Systems	Ongoing research into explainable AI for clinical trust	Acknowledges ongoing research efforts focused on leveraging explainable AI to build trust with clinicians.
Technologies, Devices, and Digital Systems	Automation of tasks with limited dependencies reduces explainability needs	Discusses how automating tasks heavily reliant on a single vital sign, like predicting a heart condition based primarily on heart rate.
Technologies, Devices, and Digital Systems	AI's potential beyond data interpretation to human interaction	Highlights AI's capability to interpret not just clinical data, but also the human element of healthcare interactions.
Work Activities and Clinical Processes	Increased technology leads to increased workload and interaction with devices	Notes that the adoption of technology, while beneficial, has increased the workload for healthcare professionals.
Work Activities and Clinical Processes	Technology has created new job opportunities within intensive care	Notes that the increased use of technology in healthcare has led to the creation of new job opportunities.

Category	Code	Description
Work Activities and Clinical Processes	Advanced therapies cause increased demand for intensive care	Notes that while advanced therapies like immunotherapy improve outcomes for conditions like cancer, they also introduce new complications requiring ICU support.
Work Activities and Clinical Processes	Expanding intensive care models increase workload outside the unit	Discusses how models like MET call systems, which extend ICU services beyond the unit.
Work Activities and Clinical Processes	Frequent machine interaction increases time spent on technical tasks	Reflects on the increasing need to interact with machines to access patient data.
Work Activities and Clinical Processes	Initial training and standardized procedures for device operation	Describes the standard introduction of new medical devices through in-service training.
Work Activities and Clinical Processes	Technology implementation does not guarantee efficiency gains	Reflects on the unsuccessful implementation of an automated dispensing system.
Work Activities and Clinical Processes	Transformation of healthcare roles through technology	The participant reflects on how the integration of robots and AI in healthcare will transform human roles, emphasizing collaboration rather than replacement.
Work Activities and Clinical Processes	Technology shifts intensive care from performing procedures to overseeing care	Role shifts from hands-on procedures to monitoring systems and making decisions with tech support.
Work Activities and Clinical Processes	Reliance on patient outcomes as primary team performance indicator in healthcare settings	The team's performance is largely assessed through patient outcomes, utilizing standardized tests and comparisons to age-related norms.
Work Activities and Clinical Processes	Standardized tests provide objective assessment of functional abilities in healthcare	The use of standardized tests, such as the Timed Up and Go Test.
Work Activities and Clinical Processes	Multidisciplinary teams utilize complex outcome measures for comprehensive assessment	Multidisciplinary teams employ complex outcome measures, such as the Functional Independence Measure, to assess a wide range of variables, including mobility, communication.
Work Activities and Clinical Processes	Identifying performance gaps through comparative data analysis using standard measures like FIM	Reflects on the process of analyzing comparative data from AROC to pinpoint discrepancies in rehabilitation outcomes between hospitals.
Work Activities and Clinical Processes	Comparing technological interventions through experimental design	Discusses using randomised controlled trials to evaluate the impact of new technologies, such as robots, on patient outcomes.

Category	Code	Description
Work Activities and Clinical Processes	Evaluating technological impact through randomised controlled trials	Explanation of using randomised controlled trials to assess the effect of a technological intervention on patient outcomes.
Work Activities and Clinical Processes	Reliance on physical labour in rehabilitation	Notes the current rehabilitation practices heavily reliant on physical labour and therapist intervention.
Work Activities and Clinical Processes	Limited scope of technology-assisted rehabilitation	Highlights the restricted use of technology in rehabilitation, specifically mentioning Wii games, balance boards, and hand-held devices.
Work Activities and Clinical Processes	Repetitive task practice directly impacts patient outcomes	Understanding the correlation between the number of repetitions of a task and the patient's recovery outcome, in neurological rehabilitation.
Work Activities and Clinical Processes	Robotic assistance reduces physical strain on healthcare professionals	Acknowledges the physical demands placed on healthcare professionals during patient care, specifically the need to manually assist patients with movement.
Work Activities and Clinical Processes	Increased patient repetition through robotic assistance	Highlights the potential for significantly increased patient repetitions during rehabilitation sessions when utilizing robotic assistance.
Work Activities and Clinical Processes	Workflow efficiency as a determinant of use	Acknowledges that if robots are time-consuming or inefficient to operate, they risk being underused or ignored within clinical environments.
Work Activities and Clinical Processes	Need for ongoing support and maintenance of complex robotic systems	Acknowledges the requirement for robust support and maintenance services for complex robotic equipment.
Work Activities and Clinical Processes	Champions addressing staff turnover through ongoing training	Acknowledges the impact of staff turnover and the need for continuous training to maintain robot utilization.
Work Activities and Clinical Processes	Robot usage depends on proximity to therapy areas	Notes that robot placement and logistical considerations significantly impact its use, including transport time and the need for nursing supervision.
Work Activities and Clinical Processes	Optimizing robot placement to minimize transport time and nursing burden	Recognizes the importance of robot placement within the gym to minimize transport time and reduce the burden on nursing staff.
Work Activities and Clinical Processes	Prioritization of patients based on clinical need and recovery potential	Explanation of the process for selecting patients to receive the new technology.
Work Activities and Clinical Processes	Balancing robotic and non-robotic therapy within daily schedules	Coordinating schedules so robotic and non-robotic therapy fit smoothly into daily rehab.

Category	Code	Description
Work Activities and Clinical Processes	Breaking down silos requires interdisciplinary communication	Recognizes the prevalence of silos within industries and the need to overcome them through improved communication and collaboration between different disciplines.
Work Activities and Clinical Processes	Recognition of the importance of iterative design and artistic creativity	Acknowledges the value of a flexible and creative approach to product development, emphasizing the need to balance technical requirements with artistic vision.
Work Activities and Clinical Processes	User-centered approach prioritizes identifying needs before implementation	Emphasizes a two-stage project design that prioritizes understanding user needs and challenges before implementing a robotic solution.
Work Activities and Clinical Processes	Loss of project continuity due to personnel changes	Acknowledges the impact of personnel changes, specifically the relocation of the lab and the graduation of a student.
Work Activities and Clinical Processes	Building trust and coordination are prerequisites for wider deployment	Notes that increased trust and improved coordination are necessary for expanding the robot's operational scope.
Work Activities and Clinical Processes	Prioritization of deliverability over ambitious project scope	Discusses the decision-making process, highlighting the prioritization of delivering tangible results over pursuing potentially exciting but technologically challenging projects.
Work Activities and Clinical Processes	Focus on evaluation as a bridge between research and practical use	Highlights the role of system evaluation as a key element in connecting research findings with the practical application and adoption of technology.
Work Activities and Clinical Processes	Workflow disruption as a barrier to technology adoption	Highlights workflow disruption as a challenge in healthcare technology implementation.
Work Activities and Clinical Processes	Iterative development through prototyping and pruning features	Advocating for a phased development approach involving prototyping and feature pruning to streamline software and focus on core functionality.
Work Activities and Clinical Processes	Clinician concerns about workflow disruption and usability	Discusses the clinician's perspective, emphasizing the importance of seamless integration and minimal disruption to existing workflows.
Work Activities and Clinical Processes	New tech often adds burden, not relief	Notes that introducing new technology often complicates existing processes and requires additional training and adaptation.
Work Activities and Clinical Processes	Quantifiable impact on clinical workflow efficiency	Highlights documented improvements in clinical workflow efficiency.
Work Activities and Clinical Processes	Leveraging expert interviews for system evaluation	Acknowledges utilizing expert interviews, similar to the interviewer's current work, as part of the system evaluation process.

Category	**Code**	**Description**
Work Activities and Clinical Processes	Project initiation driven by client needs and requirements	The process begins with direct input from healthcare clients, ranging from individual clinicians to entire hospitals.
Work Activities and Clinical Processes	Acknowledging lengthy and complex development processes	The team recognizes that the development of clinical decision support systems is a lengthy and complex undertaking.
Work Activities and Clinical Processes	Data acquisition methods vary across projects	Data collection varies by project and depends on stakeholders, context, and existing workflows.
Work Activities and Clinical Processes	Requirement gathering collaboration for project understanding	Description of a collaborative effort with a team to gather expert interviews and understand project requirements.
Work Activities and Clinical Processes	Alignment of evaluation metrics with clinical priorities	The process of selecting evaluation metrics involves aligning them with the clinical priorities and concerns.
Work Activities and Clinical Processes	Clinician adoption requires minimal training and workflow integration	Notes that successful system adoption hinges on minimizing training requirements and ensuring seamless integration into existing clinical workflows.
Work Activities and Clinical Processes	User-friendly design is crucial for system acceptance	Emphasizes the importance of user-friendliness in system design.
Work Activities and Clinical Processes	Importance of direct observation of clinical workflows	Highlights the value of developers directly observing and understanding existing clinical workflows within hospitals.
Work Activities and Clinical Processes	Developer need for continuous communication with clinical teams	Emphasizing the necessity for ongoing communication between developers and clinical teams to ensure alignment on requirements and to proactively address potential challenges.
Work Activities and Clinical Processes	Minimizing training time as a design constraint for models	Recognizes the need to design models with minimal training time required.
Work Activities and Clinical Processes	Qualitative and quantitative user feedback is essential for system understanding	Highlights the need for both qualitative and quantitative research methods to gather comprehensive user feedback.
Work Activities and Clinical Processes	Longitudinal evaluation is necessary to assess long-term system integration	Emphasizing the importance of longitudinal evaluations to understand how users adapt to the system over time and how the system integrates into.
Work Activities and Clinical Processes	Lack of practical tools for collaborative care delivery	Teams recognize the need for collaboration, but struggle due to a lack of the necessary language, systems.

Category	Code	Description
Work Activities and Clinical Processes	Balancing population data with individualized patient care	Identification of a key tension in healthcare data: the need to reconcile population-level evidence with individual patient decision-making.

Appendix C

Measurement Items for the Acceptance Study

This appendix presents the survey items used to measure each construct in the study. The items were organised according to the research model and measured using a Likert scale.

Performance Expectancy (PE) Participants rated their level of agreement with the statements presented in Table C.1.

Code	**Item**
PE1	Implementing the proposed robot in UCH's RRS system is useful.
PE2	Using the robot with the proposed design will lead to improved overall performance of RRS team.
PE3	Using the robot with the proposed design will improve the Rapid Response Team's response time.
PE4	Using the robot with the proposed design will lead to improved patient outcomes in the hospital.
PE5	Using the robot with the proposed design will reduce the errors within the Rapid Response Team's operations.
PE6	The robot will perform reliably during the RRS operations.

Table C.1: Survey items Performance Expectancy (PE)

Effort Expectancy (EE) Participants indicated their level of agreement with the statements listed in Table C.2.

Code	Item
EE1	The robot will alleviate the cognitive workload of the RRS team members during MET response.
EE2	The robot will alleviate the physical workload of the RRS team members during MET response.
EE3	Becoming proficient in using the robot would likely be straightforward for RRS members.
EE4	The voice commands and visual interface provide adequate means for interacting with the robot.
EE5	The voice commands and visual interface will be easy to work with.

Table C.2: Survey items Effort Expectancy (EE)

Social Influence (SI) Participants rated their level of agreement with the statements presented in Table C.3.

Code	Item
SI1	People who are important to me are likely to endorse the use of the robot to its full potential, encompassing autonomous operations and AI-enabled features.
SI2	People who influence my behaviour are likely to endorse the use of the robot to its full potential, encompassing autonomous operations and AI-enabled features.
SI3	People whose opinions I value are likely to endorse the use of the robot to its full potential, encompassing autonomous operations and AI-enabled features.

Table C.3: Survey items Social Influence (SI)

Facilitating Conditions (FC) Participants rated their level of agreement with the statements presented in Table C.4.

Code	Item
FC1	The hospital's physical infrastructure is well-suited for the new robotic system.
FC2	The hospital offers sufficient channels for feedback to enhance the robotic system's utilisation and maintenance.

Table C.4: Survey items Facilitating Conditions (FC)

Trust (TRU) Participants rated their level of agreement with the statements presented in Table C.5.

Code	Item
TRU1	I am willing to trust the robotic system to act without immediate human supervision.
TRU2	I would trust my own care or that of a loved one to the robotic system.
TRU3	I am confident in the hospital staff's ability to intervene if the robotic system malfunctions.
TRU4	I trust the hospital's emergency protocols for any failures of the robotic system.
TRU5	I trust that the robotic system will be used ethically for patients and staff.
TRU6	I trust the developers of the robotic system to address potential ethical dilemmas.

Table C.5: Survey items Trust (TRU)

Perceived Risk (PR) Participants assessed the likelihood of different risks associated with using the proposed robot within the hospital's RRS, as presented in Table C.6.

Code	Item
PR1	Operational Risks (e.g., malfunctioning equipment, downtime)
PR2	Technical Risks (e.g., software glitches, integration issues)
PR3	Cybersecurity Risks (e.g., data breaches, unauthorised access)
PR4	Patient Safety Risks (e.g., incorrect medication delivery, misdiagnosis)
PR5	Privacy Risks (e.g., violation of patient confidentiality, improper data handling)
PR6	Compliance Risks (e.g., non-adherence to healthcare regulations)
PR7	Human Factor Risks (e.g., resistance to change, errors in operating the robot)

Table C.6: Survey items Perceived Risk (PR)

Ethical Concerns (EC) Participants rated their level of concern regarding ethical issues associated with the proposed robot's use in the hospital's RRS, as shown in Table C.7.

Code	Item
EC1	Privacy: The adequacy of the robot's design in protecting patient confidentiality and data privacy.
EC2	Bias: The potential for built-in biases in the robot's AI algorithms affecting patient care.
EC3	Consent: The challenges in obtaining informed consent for the use of robotic assistance in treatment.
EC4	Dependency: The ethical considerations around increased reliance on technology in healthcare.
EC5	Job Displacement: Concerns about the robot replacing human jobs within the healthcare setting.
EC6	Responsibility: Clarity on accountability and liability when the robot is in operation.
EC7	Transparency: The robot's ability to provide transparent decision-making processes.

Table C.7: Survey items Ethical Concerns (EC)

Behavioural Intention (BI) Participants rated their agreement with the statements presented in Table C.8. To reflect differences between stakeholder groups, four items (BI2_RRS1 to BI2_RRS4) were developed for RRS team members, while two items (BI2_NRRS1 and BI2_NRRS2) were developed for non-RRS stakeholders, including patients, visitors, and other hospital staff. A composite indicator, BI2_CI, was subsequently calculated by averaging the relevant responses.

Code	**Item**
BI1	I would feel comfortable depending on the proposed robotic system for critical healthcare tasks.
BI2_RRS1	I am willing to be a Champion for the robotic system, advocating for its adoption and guiding its initial implementation within the hospital.
BI2_RRS2	I am willing to complete training on how to use the system.
BI2_RRS3	I am willing to join the team that will pilot the system.
BI2_RRS4	Given the choice, I am willing to use the robot over traditional tools.
BI2_NRRS1	I am open to the idea of encountering the robot within the hospital setting.
BI2_NRRS2	I am willing to be a patient treated by the medical team using the robotic system.

Table C.8: Survey items Behavioural Intention (BI)

Appendix D

Acceptance Study: Results of the Measurement Model Assessment

This appendix presents the results of the measurement model assessment.

D.0.1 Reliability and Validity of Reflective Constructs

Internal consistency reliability and convergent validity were evaluated using Cronbach's alpha, composite reliability, and average variance extracted (AVE). The corresponding results are presented in Table D.1.

	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	AVE
BI	0.82	0.82	0.92	0.85
EE	0.86	0.86	0.90	0.64
FC	0.71	0.82	0.87	0.77
PE	0.94	0.94	0.95	0.76
SI	0.91	0.91	0.94	0.85

Table D.1: Summary of Reliability and Validity Metrics for Reflective Constructs

D.0.2 Evaluation of Formative Constructs: Weights and Loadings

This section presents the significance testing results for outer weights and outer loadings. Indicator PR2 was excluded from the analysis because it had both a low outer weight and a low outer loading. The results are reported in Tables D.2 and D.3.

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics ($\left\|\frac{O}{\text{STDEV}}\right\|$)	P values
BI1 ← BI	0.53	0.54	0.02	28.85	0.00
BI2_CI ← BI	0.55	0.55	0.02	35.57	0.00
EC1 → EC	0.27	0.27	0.13	2.12	0.03
EC2 → EC	0.25	0.25	0.17	1.51	0.13
EC3 → EC	0.22	0.22	0.13	1.78	0.08
EC4 → EC	0.31	0.29	0.17	1.75	0.08
EC5 → EC	0.36	0.33	0.11	3.24	0.00
EC6 → EC	0.08	0.08	0.19	0.42	0.68
EC7 → EC	-0.07	-0.07	0.18	0.38	0.70
EE1 ← EE	0.28	0.28	0.03	10.11	0.00
EE2 ← EE	0.24	0.24	0.03	7.79	0.00
EE3 ← EE	0.25	0.25	0.03	7.86	0.00
EE4 ← EE	0.22	0.22	0.03	8.35	0.00
EE5 ← EE	0.26	0.27	0.03	7.90	0.00
FC1 ← FC	0.69	0.68	0.21	3.29	0.00
FC2 ← FC	0.44	0.40	0.25	1.77	0.08
PE1 ← PE	0.19	0.19	0.01	14.52	0.00
PE2 ← PE	0.19	0.19	0.01	13.41	0.00
PE3 ← PE	0.17	0.17	0.01	13.06	0.00
PE4 ← PE	0.21	0.22	0.02	13.69	0.00
PE5 ← PE	0.19	0.19	0.01	15.15	0.00
PE6 ← PE	0.19	0.19	0.02	12.49	0.00
PR1 → PR	0.43	0.40	0.20	2.21	0.03
PR2 → PR	-0.21	-0.22	0.21	1.02	0.31
PR3 → PR	-0.15	-0.12	0.18	0.79	0.43
PR4 → PR	0.67	0.61	0.22	3.02	0.00
PR5 → PR	0.32	0.30	0.21	1.52	0.13
PR6 → PR	0.08	0.08	0.19	0.43	0.66
PR7 → PR	0.09	0.10	0.20	0.47	0.64
SI1 ← SI	0.36	0.36	0.02	17.03	0.00
SI2 ← SI	0.36	0.36	0.02	14.70	0.00
SI3 ← SI	0.37	0.37	0.02	15.45	0.00
TRU1 → TRU	0.20	0.17	0.25	0.81	0.42
TRU2 → TRU	0.65	0.64	0.21	3.04	0.00
TRU3 → TRU	-0.01	0.00	0.15	0.07	0.95
TRU4 → TRU	-0.03	-0.02	0.17	0.18	0.85
TRU5 → TRU	0.17	0.18	0.15	1.12	0.26
TRU6 → TRU	0.14	0.13	0.15	0.90	0.37

Table D.2: Outer weights used to assess indicator relevance for formative constructs

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics ($\left\|\frac{O}{STDEV}\right\|$)	P values
BI1 ←BI	0.92	0.92	0.02	51.22	0.00
BI2_CI ←BI	0.92	0.92	0.02	49.90	0.00
EC1 → EC	0.77	0.74	0.09	8.31	0.00
EC2 → EC	0.55	0.53	0.15	3.61	0.00
EC3 → EC	0.73	0.71	0.08	8.84	0.00
EC4 → EC	0.81	0.78	0.08	10.46	0.00
EC5 → EC	0.65	0.61	0.10	6.27	0.00
EC6 → EC	0.68	0.66	0.11	5.99	0.00
EC7 → EC	0.66	0.63	0.12	5.71	0.00
EE1 ←EE	0.85	0.85	0.03	27.29	0.00
EE2 ←EE	0.71	0.71	0.07	10.01	0.00
EE3 ←EE	0.79	0.79	0.05	15.15	0.00
EE4 ←EE	0.80	0.80	0.05	15.64	0.00
EE5 ←EE	0.83	0.83	0.04	21.15	0.00
FC1 ←FC	0.93	0.92	0.11	8.57	0.00
FC2 ←FC	0.82	0.77	0.20	4.20	0.00
PE1 ←PE	0.88	0.88	0.03	34.61	0.00
PE2 ←PE	0.85	0.85	0.03	26.48	0.00
PE3 ←PE	0.87	0.86	0.04	23.86	0.00
PE4 ←PE	0.89	0.89	0.02	39.05	0.00
PE5 ←PE	0.88	0.87	0.03	26.63	0.00
PE6 ←PE	0.87	0.87	0.03	28.61	0.00
PR1 → PR	0.54	0.49	0.16	3.26	0.00
PR2 → PR	0.27	0.25	0.16	1.64	0.10
PR3 → PR	0.48	0.44	0.15	3.13	0.00
PR4 → PR	0.90	0.84	0.08	10.86	0.00
PR5 → PR	0.63	0.60	0.15	4.30	0.00
PR6 → PR	0.50	0.47	0.16	3.08	0.00
PR7 → PR	0.56	0.52	0.16	3.42	0.00
SI1 ←SI	0.94	0.94	0.01	71.81	0.00
SI2 ←SI	0.91	0.91	0.02	37.99	0.00
SI3 ←SI	0.91	0.91	0.04	24.26	0.00
TRU1 → TRU	0.90	0.87	0.06	14.31	0.00
TRU2 → TRU	0.97	0.94	0.03	28.82	0.00
TRU3 → TRU	0.40	0.39	0.16	2.51	0.01
TRU4 → TRU	0.50	0.49	0.14	3.60	0.00
TRU5 → TRU	0.70	0.68	0.10	7.22	0.00
TRU6 → TRU	0.67	0.65	0.10	6.75	0.00

Table D.3: Outer loadings for assessing indicator contributions to formative constructs

D.0.3 Variance Inflation Factors for Formative Constructs

Variance Inflation Factor (VIF) values were computed to assess potential multicollinearity among the formative indicators. The results are reported in Table D.4.

	VIF
BI1	1.953
BI2_CI	1.953
EC1	1.945
EC2	1.458
EC3	1.838
EC4	2.350
EC5	1.406
EC6	2.503
EC7	2.467
EE1	2.471
EE2	1.749
EE3	1.923
EE4	2.415
EE5	2.590
FC1	1.441
FC2	1.441
PE1	3.208
PE2	2.753
PE3	3.121
PE4	3.293
PE5	3.204
PE6	2.972
PR1	1.973
PR2	1.878
PR3	1.932
PR4	2.338
PR5	1.867
PR6	1.407
PR7	1.521
SI1	3.842
SI2	3.036
SI3	2.815
TRU1	3.821
TRU2	3.727
TRU3	1.767
TRU4	2.159
TRU5	2.141
TRU6	2.150

Table D.4: VIF values for the assessment of the formative constructs

D.0.4 Heterotrait-Monotrait (HTMT) Ratio for Formative Constructs

The Heterotrait-Monotrait (HTMT) ratio was used to assess discriminant validity among the constructs. This assessment examined whether each construct was sufficiently distinct from the others in the model.

	BI	EE	FC	PE	SI
BI					
EE	0.799				
FC	0.359	0.362			
PE	0.846	0.744	0.239		
SI	0.828	0.651	0.498	0.695	

Table D.5: HTMT Ratio Matrix for Assessing Discriminant Validity among Formative Constructs

Appendix E

RRS Case Study: Codebook

Category	Code	Description
Operational Challenges in HERO Responses	Limited diagnostic capability at subacute sites	Insufficient access to diagnostic tools , limiting rapid assessment and decision-making for deteriorating patients.
Operational Challenges in HERO Responses	Delays in transfer and escalation	Slow or inefficient pathways for transferring patients to higher levels of care or escalating clinical concerns.
Operational Challenges in HERO Responses	Difficulty managing complex clinical presentations	Challenges associated with assessing and treating patients whose deterioration is complicated by obesity, cognitive impairment, or atypical symptoms.
Operational Challenges in HERO Responses	Communication breakdown in emergencies	Disrupted or ineffective communication during emergency responses due to noise, urgency, or multiple competing interactions.
Operational Challenges in HERO Responses	Unclear team roles during response	Lack of clear role allocation during HERO events, leading to confusion, duplication, or inefficiency.
Operational Challenges in HERO Responses	Challenges caring for non-verbal patients	Difficulty assessing and responding to patients who cannot clearly communicate symptoms or needs.
Operational Challenges in HERO Responses	Physical burden of retrieving and moving equipment	Time-consuming and physically demanding effort required to locate, transport, or set up equipment during urgent care.
Operational Challenges in HERO Responses	Trolley clutter and organization problems	Poor trolley layout or cluttered storage that makes emergency equipment harder to find quickly.
Operational Challenges in HERO Responses	Restocking workload and cognitive load	Mental and physical burden associated with manually checking, replacing, and organizing emergency stock.

Category	Code	Description
Operational Challenges in HERO Responses	Crowding and environmental chaos during calls	Emergency response environments characterized by overcrowding, distraction, or disorder that interferes with care delivery.
Existing Resources and Workflow Infrastructure	Reliance on Digital Health Record (DHR)	Dependence on the DHR as the primary system for documenting, reviewing, and coordinating patient care.
Existing Resources and Workflow Infrastructure	Use of MEWS and protocol-based escalation	Use of structured scoring tools or clinical pathways to identify deterioration and guide escalation.
Existing Resources and Workflow Infrastructure	Emergency trolley and grab-bag dependence	Reliance on trolleys, bags, and portable emergency kits as essential resources in HERO responses.
Existing Resources and Workflow Infrastructure	Dependence on mobile computing devices	Need for portable computers or ward-based devices to access records, charts, or clinical information during emergencies.
Existing Resources and Workflow Infrastructure	Limited point-of-care testing capacity	Restricted availability of bedside testing, reducing the ability to obtain rapid clinical information.
Existing Resources and Workflow Infrastructure	Manual stock and expiry tracking systems	Stock and expiry monitoring processes that rely on manual checking, recording, or visual inspection.
Existing Resources and Workflow Infrastructure	Continued reliance on paper or manual scribing	Ongoing use of handwritten notes or manual data entry during emergency responses.
Existing Resources and Workflow Infrastructure	Workforce support through junior or mixed-skill teams	Dependence on staff with varying levels of experience and expertise to support emergency response activity.
Proposed Technological Enhancements	Point-of-care ultrasound for bedside diagnostics	Use of portable ultrasound to improve bedside diagnostic capability and support faster clinical decisions.
Proposed Technological Enhancements	AI-assisted deterioration detection	Use of artificial intelligence to identify early signs of patient deterioration and support escalation.
Proposed Technological Enhancements	Predictive signal analysis for subtle clinical changes	Use of digital systems to detect subtle physiological trends that may indicate early decline before obvious deterioration.
Proposed Technological Enhancements	Inter-hospital predictive alert systems	Automated systems that notify receiving teams about incoming deteriorating patients before transfer or arrival.

Category	Code	Description
Proposed Technological Enhancements	Autonomous robotic trolley navigation	Robotic movement of emergency trolleys or equipment to clinical areas without manual transport.
Proposed Technological Enhancements	Automated stock, restocking, and expiry management	Digital systems that identify missing, low, or expired stock and support automatic replenishment processes.
Proposed Technological Enhancements	Equipment location tracking	Technology that identifies the location of mobile or shared equipment to reduce searching time.
Proposed Technological Enhancements	Automated documentation and chart population	Systems that transfer observations or structured clinical information directly into charts or records.
Proposed Technological Enhancements	Voice-to-text or AI-supported scribing	Speech recognition or AI transcription used to support documentation during emergency events.
Proposed Technological Enhancements	Wearable continuous monitoring devices	Compact monitoring devices that provide continuous real-time physiological data without repeated manual measurement.
Proposed Technological Enhancements	AI-guided workflows and digital cognitive aids	On-screen prompts, pathways, or algorithm-based guidance designed to support prioritization and clinical workflow during emergencies.
Proposed Technological Enhancements	Task-assistive retrieval or voice-activated systems	Technology that assists with practical tasks such as retrieving equipment, opening storage, or responding to verbal commands.
Attitudes Toward Innovation and AI	AI as clinician support, not replacement	View of AI as a decision-support tool that complements rather than replaces clinician judgment.
Attitudes Toward Innovation and AI	Strong enthusiasm for innovation	Clear optimism and willingness to adopt new technologies in clinical practice.
Attitudes Toward Innovation and AI	Technology seen as inevitable future direction	Perception that AI, automation, and robotics are a natural or unavoidable part of future healthcare practice.
Attitudes Toward Innovation and AI	Conditional acceptance based on practical benefit	Openness to innovation when it clearly reduces workload, improves efficiency, or provides visible clinical value.
Attitudes Toward Innovation and AI	Preference for automation of routine tasks	Support for using technology to manage repetitive, logistical, or administrative work rather than core clinical judgment.
Attitudes Toward Innovation and AI	Skepticism toward full autonomy	Cautious attitude toward fully autonomous systems, especially where independent action may reduce human control.

Category	Code	Description
Attitudes Toward Innovation and AI	Human oversight remains essential	Expectation that clinicians should continue to supervise, verify, or remain accountable for technology-supported decisions.
Attitudes Toward Innovation and AI	Innovation linked to better patient-centered care	Belief that automation can free staff from menial tasks and increase time available for direct patient care.
Implementation Barriers and Risks	Regulatory and medico-legal uncertainty	Concerns about unclear legal responsibility, governance, or regulatory approval for AI and automated systems.
Implementation Barriers and Risks	Privacy and information governance concerns	Concerns about confidentiality, data protection, and secure handling of patient information within digital systems.
Implementation Barriers and Risks	Alert fatigue and intrusive system design	Risk that excessive prompts, notifications, or poorly designed interfaces may overwhelm staff and reduce usability.
Implementation Barriers and Risks	Technical unreliability and hardware failure	Lack of confidence in technology due to malfunctioning devices, broken hardware, or inconsistent performance.
Implementation Barriers and Risks	Need for ongoing technical support and maintenance	Requirement for sustained technical assistance, servicing, troubleshooting, and system upkeep after implementation.
Implementation Barriers and Risks	Staff resistance to change	Reluctance or pushback from staff who are hesitant to alter established work practices.
Implementation Barriers and Risks	Generational divide in technology acceptance	Perceived differences in willingness to adopt technology across age groups or career stages.
Implementation Barriers and Risks	Training burden and learning curve	Additional education, familiarization, and adjustment required before staff can confidently use new systems.
Implementation Barriers and Risks	Budget and resourcing constraints	Financial and staffing limitations that restrict implementation, maintenance, or scale-up of innovation.
Implementation Barriers and Risks	Difficulty scaling change across organizations	Challenges extending innovation across multiple hospitals, services, or settings with different capacities and priorities.
Implementation Barriers and Risks	Risk of glitches in high-stress settings	Concern that technology may fail, slow down, or behave unpredictably in urgent or high-pressure clinical situations.
Organizational Capacity for Change	Innovation positioned as an organizational value	Organizational culture that explicitly supports innovation, improvement, or experimentation.
Organizational Capacity for Change	Governance structures support implementation	Presence of committees, review processes, or leadership mechanisms that enable oversight of change.
Organizational Capacity for Change	Teaching or research identity enables trials	Institutional identity as a teaching or research site that supports piloting and testing new technologies.

Category	**Code**	**Description**
Organizational Capacity for Change	Flexible and adaptable local culture	Workplace culture characterized by openness, responsiveness, and willingness to adjust to new systems or practices.
Organizational Capacity for Change	Previous successful change builds confidence	Confidence in future implementation based on prior experience managing major organizational or technological change.
Organizational Capacity for Change	Younger workforce drives adoption	Perception that younger staff are more likely to champion and normalize technology use.
Organizational Capacity for Change	Sustainability threatened by turnover and limited expertise	Difficulty maintaining innovation over time due to staff turnover, loss of expertise, or limited long-term support.
Organizational Capacity for Change	Readiness is present but uneven	General openness to change that varies across teams, sites, or staff groups.

Appendix F

Lokomat Case Study: Codebook

Category	Code	Description
General	Participant role and responsibility	Participants describe their roles, responsibilities, and daily tasks in the gym, especially their involvement with the Lokomat.
Challenges and Barriers	Adjustment time as a potential barrier to use	Time-consuming adjustments can make the Lokomat harder to use regularly and may lead to underuse.
Challenges and Barriers	Challenge with lack of research for practical use	Limited practical evidence on best use makes it difficult to apply the Lokomat confidently in clinical settings.
Challenges and Barriers	Challenges with forced normal gait pattern	Standard gait settings may not suit every patient's condition and can conflict with individual needs.
Challenges and Barriers	Challenges with measurements and patient body variability	Inconsistent measurements and changes in a patient's body can make setup more difficult.
Changes and New Things	Emergency and safety plans	Comments on developing, using, and regularly reviewing safety procedures and emergency plans for Lokomat sessions.
Changes and New Things	New policies and procedures	Comments on guidelines, pre-screening processes, and hybrid therapy plans created to support Lokomat use.
Changes and New Things	New responsibilities	Describes new tasks such as scheduling, training, and administration related to Lokomat operations.
Changes and New Things	New roles and positions	Comments on creating new roles for training, research, and succession planning related to the Lokomat.
Changes and New Things	Preparation for adverse events	Planning, practice, and readiness for handling medical emergencies during Lokomat sessions.
Changes and New Things	Reporting of adverse events	Describes how adverse events are documented, reported, and aligned with hospital requirements.

Category	**Code**	**Description**
Changes and New Things	Shifting therapy model in the gym because of the robot	Changes in how therapy is delivered, including staff roles and combining Lokomat sessions with other treatments.
Changes and New Things	Using Lokomat is not a replacement for other therapies	The Lokomat is used alongside traditional therapies, not as a complete replacement.
Decision Making	Confidence in staff's capacity in adapting to technical complexity	Confidence in staff's ability to manage the Lokomat's technical demands was an important factor in the decision to purchase it.
Decision Making	Consultations with experts	Discussions with robotics or industry experts to explore how healthcare robots could be used.
Decision Making	Decision makers being questioned about their decision	Decision makers were asked to justify adopting the Lokomat, especially in the context of staffing pressures.
Decision Making	Decision making - broad patient usability	The importance of choosing a device that can be used with a wide range of patients.
Decision Making	Decision making - compliance with governance and standards	The importance of choosing a device that meets hospital governance requirements and clinical standards.
Decision Making	Decision making - ease of patient handling	The importance of choosing a robot that is easy for staff to use when setting up and removing patients.
Decision Making	Decision making - hopes and fears	Hopes that the robot would be widely used across roles, and concerns that its use might be limited to physiotherapists.
Decision Making	Decision making - how the robot was selected	The process of selecting the Lokomat, including demonstrations, comparisons, and funding considerations.
Decision Making	Decision making - importance of accuracy	The importance of precise and accurate practice to support good clinical outcomes.
Decision Making	Decision making - importance of joint control	The importance of the robot being able to control individual joints.
Decision Making	Decision making - not being concerned with installation	Installation was not a major concern as long as the robot could fit in the available space.
Decision Making	Decision making - predicting impact on workflows	Consideration of how the robot would affect workflows and which stakeholders needed to be involved.
Decision Making	Decision making - stakeholder consultation	Involving key stakeholders in planning the robot's location, operation, and staffing needs.

Category	Code	Description
Decision Making	Decision making about the robot - initial motivation	Early reasons for adopting the robot, including strengthening research, encouraging innovation, and creating an attractive workplace.
Decision Making	Decision making considerations	Broader decision-making issues such as balancing clinical and research use, improving workflows, and reducing the risk of underuse.
Decision Making	Decision making process - importance of research	The role of research evidence in shaping the decision to adopt the Lokomat.
Decision Making	Lokomat and robotics research	Research was seen as important for securing future funding and building credibility for the technology.
Decision Making	Procurement process - details	Details about how the Lokomat was purchased, including approvals, funding pathways, and vendor-related steps.
Ethics and Risks	Comments on concerns about job displacement	Staff showed little concern that robots would replace their jobs.
Ethics and Risks	Comments on robot's safety	Perceptions that the Lokomat is safe, supported by harness systems and the absence of reported safety incidents.
Ethics and Risks	No thinking about risks because of TGA approvals	Some participants were not very concerned about safety risks because they trusted approval processes such as TGA requirements.
Ethics and Risks	Risks of not using the robot	The risk that the Lokomat becomes underused because of complexity, time demands, or staff shortages, reducing its value.
Expectations and Reality	Comments on concerns prior to training	Staff concerns before training included workload, emergency management, and not having enough detailed information about the Lokomat.
Expectations and Reality	Comments on misalignment of initial expectations	Staff expected the Lokomat to save time, but instead found that it often required more effort and increased workload.
Expectations and Reality	Expectations - increasing motivation	Expectations that the Lokomat's game-like features would improve patient motivation and engagement.
Expectations and Reality	Expectations - increasing therapy intensity	Expectations that the Lokomat would increase the duration and intensity of therapy.
Funding	Funding - health services not having money	Difficulty securing funding for the Lokomat because health service budgets were limited and external grants were needed.
Funding	Funding - importance of domain expertise	Specialist knowledge in the field played an important role in securing funding.

Category	**Code**	**Description**
Funding	Funding - using multiple sources	A funding strategy that combined sources such as government grants and hospital foundation support.
Funding	Funding and research	Research was linked with clinical care to help justify and secure funding.
Funding	Lobbying and politics to get funding for new positions	Efforts to secure funding for robotics-related positions through lobbying and political advocacy.
Interface	Challenges with biometric feedback to physios	The Lokomat's biometric feedback can be hard for physiotherapists to interpret because the graphs are not always clear.
Interface	Interface - information provided to physios by robot	The robot provides detailed information that can support physiotherapists during treatment.
Interface	Interface - patient-robot interface	The Lokomat is described as user-friendly from the patient's point of view.
Interface	Interface - hassle-free interaction with Lokomat	The Lokomat interface is described as simple and easy for both operators and patients to use.
Lokomat vs Traditional Therapy	Comments on robot's effectiveness	The Lokomat appears to support positive patient outcomes and improved gait, although more evidence is still needed.
Lokomat vs Traditional Therapy	Comparison - robot-assisted vs conventional rehabilitation	Perceived differences between robotic and traditional rehabilitation include longer sessions, more precise movement, more repetitions, less manual effort, and better patient engagement.
Organization	Comparison - UCH vs acute hospitals	Differences between UCH and acute hospitals in structure, priorities, and the way new technology is used.
Organization	Impact of the robot on UCH	The robot has had a positive effect on UCH by attracting students and professionals who want to study or work there.
Organization	Organization - UCH's innovativeness	UCH is described as progressive and innovation-focused, supported by its identity as a new university-linked rehabilitation hospital.
Organization	Risk taking at UCH and health services	UCH and ACT health services are described as generally risk-averse.
Organization	UCH and UC	The relationship between UCH and UC, including collaboration, shared goals, and links between practice and academia.
Organization	UCH's readiness	UCH's level of preparedness to adopt and support the Lokomat in practice.

Category	Code	Description
Organization	UCH's resiliency	UCH's ability to adapt, recover, and continue using the Lokomat despite challenges.
Patients	Challenges with non-verbal patients	It can be difficult to assess discomfort or problems during sessions when non-verbal patients cannot communicate clearly.
Patients	Motivation - gamified patient engagement and motivation	Game-like features help improve patient motivation and engagement during Lokomat therapy.
Patients	Patient conditions	The kinds of patient conditions that are seen as suitable, or not suitable, for Lokomat therapy.
Patients	Patient selection procedure	The process used to identify which patients are appropriate for Lokomat therapy.
Patients	Patient's involvement	The extent to which patients take part in decisions, setup, and active engagement during Lokomat therapy.
Patients	Patients' over-optimism about the robot	Cases where patients have overly positive or unrealistic expectations about what the Lokomat can do.
Patients	Patient's rehab experience	Patients generally report a better overall rehabilitation experience when using the Lokomat.
Patients	Patients' reluctance to use the robot	Occasional hesitation or reluctance from patients about using the robot.
Patients	Positive patient feedback	Patients consistently report enjoying Lokomat sessions and having positive experiences.
Patients	Role of patient's family, friends and caregivers	Family, friends, and caregivers are not essential to Lokomat therapy, but they can still provide useful support.
Physiotherapists	Foundational knowledge requirements	The basic knowledge and skills needed to operate the Lokomat safely and effectively.
Physiotherapists	Importance of clinical reasoning	Clinical reasoning is important for troubleshooting issues and making good decisions about patient care.
Physiotherapists	Motivation - desirability for the physiotherapists	Physiotherapists see the Lokomat as a useful and appealing tool for both therapy and professional growth.
Robotics and Physiotherapy	Bias - robots for physiotherapy vs other medical disciplines	Physiotherapy robots may face more scrutiny and more funding barriers than robots used in areas such as surgery.
Robotics and Physiotherapy	Comments on robots in the field of rehabilitation	Different views on how accepted and useful robots are within rehabilitation.

Category	**Code**	**Description**
Robotics and Physiotherapy	Healthcare robotics in Australia vs rest of the world	Australia is seen as using rehabilitation robots less widely than some other countries.
Robotics and Physiotherapy	Physiotherapy vs occupational therapy	The different roles of physiotherapists and occupational therapists in using robotic devices.
Robotics and Physiotherapy	Robotics in physiotherapy curriculum	Efforts to include robotic therapy in physiotherapy education and training.
Staffing and Utilization	Challenges with staff allocation and impact on workload	Using the Lokomat takes significant staff time, often requiring two physiotherapists per session and increasing overall workload.
Staffing and Utilization	Consequences of under-utilization	Risks of underusing the Lokomat include loss of staff skills, reduced confidence, and poor return on investment.
Staffing and Utilization	Lokomat is not labour-saving; it creates extra labour	Although the Lokomat may improve therapy, it does not reduce staffing demands and can create extra work.
Resistance to Change	Robot not being used because of loss of one staff member	Losing a single trained staff member could stop Lokomat use entirely.
Resistance to Change	Succession plans	Comments on planning for future leads and training others so Lokomat use can continue over time.
Support	Challenges with lack of support	Limited clinical expertise and poor access to shared resources make it harder to troubleshoot Lokomat issues.
Support	Support from Hocoma	Details of the support provided by Hocoma after the initial training sessions.
Support	Support from peers	Teams rely on colleagues, collaboration, and trial-and-error to solve clinical and technical problems.
Support	Support from UCH	Limited support from UCH, especially around staffing shortages, affects full Lokomat integration.
Therapy Session	Therapy session - coordination among 2 physiotherapists	Describes how tasks are shared between the two staff members operating the Lokomat.
Therapy Session	Therapy session - coordination and scheduling of the sessions	Describes how sessions are planned and scheduled to reduce disruption in the gym.
Therapy Session	Therapy session - details	General details about routine Lokomat therapy sessions.
Therapy Session	Therapy session - excluding patients because of additional exclusion criteria	Describes which patients may be excluded from Lokomat therapy because of extra screening criteria.

Category	Code	Description
Therapy Session	Therapy session - initial setup	Details about first-time Lokomat sessions and the setup required.
Therapy Session	Therapy session - pre-session preparation	Therapists coordinate with nurses and families to make sure patients are ready before the session begins.
Therapy Session	Therapy session - setup for returning patients	Details about follow-up sessions for returning patients, which are usually faster because previous settings are saved.
Tracking	Tracking - utilization metrics for device and staffing	Data collected to assess whether the robot improves efficiency or adds to staffing burden.
Tracking	Tracking - patient outcome tracking and documentation	Details of the data collected to track patient outcomes and document progress.
Trade-offs	Comments on patient benefits over workload reduction	The Lokomat may improve therapy for individual patients, but it does not reduce staff workload.
Trade-offs	Patient flow vs robot utilization	The trade-off between keeping patient flow moving and making full use of the Lokomat.
Training	Training by Hocoma - advanced training	Hocoma uses a phased training model, with initial training, practice over time, and advanced training to build confidence and prepare staff to train others.
Training	Training by Hocoma - areas of improvement	Suggested improvements to Hocoma's training, such as better preparation materials and more patient-focused practice.
Training	Training by Hocoma - details	Detailed information about the two-day training provided by Hocoma.
Training	Training new robot operators	The process used to train and onboard new Lokomat operators.
Training to Practice	Challenges with optimal clinical outcomes	Challenges in adjusting machine settings to achieve the best clinical results beyond basic setup and safety.
Training to Practice	From training to practice	The transition from learning how to use the Lokomat to applying it in real clinical practice.