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A TECHNO-ANTHROPOLOGICAL INVESTIGATION OF ROBOTS WORKING WITH SERVICE STAFF IN HOSPITALS

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KRISTINA TORNBJERG ERIKSEN

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ENGLISH SUMMARY

This work constitutes a techno-anthropological exploration of the intersection of robot technology, human staff and the context and environments in which they function: in this case, Danish hospitals. Danish hospitals are increasingly using robot technology to support and alleviate the workload of staff in various areas of work. When robots either fully or partially take over professional tasks, it often leads to unpredictable changes that are important to gain insight into. One justification for automating tasks with robots is that certain robots can perform tasks better or faster than humans, take over trivial assignments, and relieve employees. The vision is that robots will lighten the workload and save time for the staff, who can use the freed-up time for other tasks. However, there is a lack of knowledge in the field, including how the staff perceives robot technology and how robots affect work. Additionally, there is a knowledge gap in terms of the synergies between the visions and expectations of developers, hospital managements and policy makers regarding automation and robots - and reality. It is in these gaps, this PhD project operates. The project has generated knowledge in the field through fieldwork conducted at three Danish hospitals, scrutinizing the dynamics between mobile robots and various service professionals in their work with, or in relation to, the robots. In addition, a scoping review study has been conducted.

This dissertation sets off with the contextual background, discussing the presence and significance of robots in Danish society and the political landscape. The focus then shifts to the role of robots in new super hospitals in Denmark, with particular attention to hospital logistics and their impact on daily operations. After that, the concept of robots is defined, and the cultural perspectives that shape robot definitions are considered, along with exploring the origin and purpose of robots in society. The subsequent sections delve into the specific domain of robots in hospitals, examining robot types and evolving perspectives on robots and their real-world operations. Further, the power of technological innovations is emphasised, highlighting the potential for robots to bring about transformative changes in hospitals.

The research questions centres around how collaboration between service staff and mobile robots unfold in Danish hospitals, how empirical findings from different hospital sites can contribute to conceptual insights about human-robot collaboration in hospitals and how evidence from the scientific literature can be used to create a tentative, conceptual framework for human-robot collaboration in hospitals. These are followed by an outlining of the scientific approaches and research methods employed, including pragmatism, phenomenology, philosophy of technology, and postphenomenology. The research design encompasses a range of ethnographic inspired data collection techniques such as fieldwork, participant observation, interviews, guided tours, and shadowing.

The conceptual and theoretical frameworks have respectively four pins: one concerning human-robot collaboration and interaction, including related work within the field, comprising robots in the wild and human non-use of technology. The second pin evolves around human-

technology relations and interactions, including mediation theory and social construction of technology. The third pin is concerned with work; practice theory; robots as agents of change in work, CSCW, articulation work and plans and situated actions. The fourth pin revolves around a model for applying change, the Leavitt diamond model. These frameworks provide foundation for understanding the complexities of human-robot collaboration that are outlined in the Findings.

The Findings section presents the outcomes of the studies conducted, offering insights into the dynamics between mobile robots and hospital service staff including practical implications of robots in hospitals and the challenges associated with humans and robots working together.

The Discussion section concerns how hospital staff experience mobile robots, how robots impact work and finalises by discussing the alignment of expectations towards robots, with real-world context.

In the Conclusion, the takeaways from the PhD project are outlined. As the project have delved into the realm of human-robot collaboration within hospital settings, shedding light on the intricate nature of these collaborations in real-world scenarios, one of the key takeaways is the presence of various challenges that need to be addressed for successful cooperation. Unrealistic expectations, increased staff workload, and socio-technical factors all pose significant hurdles. To overcome these challenges, it is crucial to establish a clear division of responsibility for the robots, among human staff. Additionally, ensuring the presence of suitable infrastructure and dedicated support personnel is vital to facilitate effective collaboration. By personalising interactions and creating environments that cater to the specific needs of both humans and robots, the quality of task execution can be enhanced, fostering a stronger sense of teamwork. A comprehensive understanding of the complexities involved in human-robot collaboration can aid in guiding the implementation, deployment and integration of robots within hospital environments. This understanding can lead to improved effectiveness and increased acceptance among staff, and it is vital to recognise the implications and challenges associated with incorporating robots into human work environments. By doing so, optimal conditions for collaboration can be established, enabling successful integration of robots in hospitals.

This exploration of HRC in Danish hospitals is undertaken from a techno-anthropological perspective, aiming to provide a nuanced understanding of the complex dynamics between human staff and mobile robots in the wild: in hospitals.

DANSK RESUMÉ

Følgende PhD-afhandling udgør en teknoantropologisk udforskning af krydsfeltet mellem robotteknologi, menneskeligt personale og de kontekster og miljøer, de fungerer i. I dette tilfælde på danske hospitaler. Projektet sigter mod at give en nuanceret forståelse af de komplekse dynamikker mellem hospitalspersonale og mobile robotter, hvilket synes relevant, da danske hospitaler i stigende grad anvender robotteknologi til at støtte og aflaste personalet inden for forskellige arbejdsområder. Når robotter enten helt eller delvist overtager opgaver, kan det føre til uforudsigelige ændringer, som det er vigtigt at opnå indsigt i. Begrundelserne - visionerne om man vil - for at tage robotter i anvendelse er, at visse robotter kan udføre opgaver bedre eller hurtigere end mennesker, påtage sig trivielle opgaver og lette arbejdsbyrden for medarbejderne. Forventningen er, at robotter vil lette arbejdsbyrden og spare tid for personalet, som kan anvende den frigjorte tid til andre opgaver, samt aflastes fysisk. Der er dog manglende viden på området, herunder omkring hvordan personalet opfatter robotteknologi og hvordan robotter påvirker arbejdet. Derudover er der et videnshul omkring synergierne mellem robotudviklernes, politikernes og hospitalsledelsernes visioner og forventninger til automatisering og robotter - og virkeligheden på hospitaler. Det er i disse huller, nærværende Ph.D.-projekt opererer. Projektet har, foruden et reviewstudie, genereret viden på området gennem feltarbejde udført på tre danske hospitaler, hvor dynamikken mellem mobile robotter og forskellige servicefagfolk i deres arbejde med - eller i forhold til - robotterne er undersøgt.

Denne afhandling starter med at udfolde den kontekstuelle baggrund for samarbejdet mellem hospitalspersonale og mobile robotter, ved gennemgang af brugen og betydningen af robotter i det danske samfund og i det politiske landskab. Fokus skifter derefter til robotternes rolle på nye supersygehuse i Danmark, med særlig opmærksomhed på sygehuslogistik og teknologiens indvirkning på daglig drift. Derefter defineres begrebet *robot*, og de kulturelle perspektiver, der præger robotdefinitioner, bliver taget til efterretning. Samtidig udforskes oprindelsen og formålet med robotter i samfundet. De følgende afsnit dykker ned i det specifikke domæne for robotter på hospitaler og undersøger robottyper samt udviklingen af perspektiver på robotter og deres operationer i den virkelige verden. Derudover udfoldes betydningen af teknologiske innovationer, og begreberne ”human-robot collaboration”, ”human-robot cooperation” samt ”human-robot co-existence” gennemgåes.

Dernæst følger problemformuleringen, der fokuserer på, hvordan samarbejdet mellem servicepersonale og mobile robotter udfolder sig på danske hospitaler, hvordan empiriske resultater fra forskellige hospitalssteder kan bidrage til konceptuel indsigt i samarbejdet mellem mennesker og robotter på hospitaler, samt hvordan evidens fra den videnskabelige litteratur kan anvendes til at skabe en foreløbig, konceptuel ramme for samarbejdet mellem mennesker og robotter på hospitaler.

Problemformuleringen efterfølges af et kapitel, der fungerer som en oversigt over de videnskabsteoretiske tilgange og forskningsmetoder, der anvendes, herunder pragmatisme,

fænomenologi, teknologifilosofi og post-fænomenologi. Forskningsdesignet omfatter en række etnografisk inspirerede metoder til dataindsamling, inklusiv feltarbejde, deltagerobservation, interviews, guidede ture og *shadowing*.

Hernæst bliver de konceptuelle og teoretiske rammer for PhD-projektet udfoldet gennem fire nøgleelementer. Det første nøgleelement omhandler samarbejde og interaktion mellem mennesker og robotter, inklusiv eksisterende, relateret forskning indenfor feltet, herunder robotter i det virkelige liv og menneskers ikke-brug af teknologi. Det andet nøgleelement er udviklingen af forholdet og interaktionen mellem mennesker og teknologi, herunder mediationsteori og den sociale konstruktion af teknologi. Det tredje nøgleelement omhandler arbejde, herunder praksisteori, robotter som forandringsagenter i arbejdet, CSCW (Computer Supported Cooperative Work), *articulation work*, samt planer og situationsbestemte handlinger. Det fjerde nøgleelement omfatter en model til implementering af forandringer. Disse rammer danner grundlag for at forstå kompleksiteten i samarbejdet mellem mennesker og robotter, som er beskrevet i resultaterne.

Dette efterfølges af afhandlingens resultatafsnit. Heri præsenteres resultaterne af de udførte studier og giver indblik i dynamikken mellem mobile robotter og hospitalspersonale, inklusiv de praktiske implikationer af robotter på hospitaler og udfordringerne ved at mennesker og robotter arbejder sammen.

Diskussionafsnittet omhandler hvordan hospitalspersonale oplever mobile robotter, hvorledes robotter påvirker arbejde – og diskuterer hvordan forventningerne til robotter på hospitaler, harmonerer med den faktiske virkelighed på danske hospitaler.

PhD-projektet dykker ned i samarbejdet mellem mennesker og robotter inden for hospitalsmiljøer og belyser den komplekse karakter af disse samarbejder i virkelighedens verden. En af hovedpointerne i konklusionen er tilstedeværelsen af forskellige udfordringer, der skal tackles for at opnå succesfuldt samarbejde. Urealistiske forventninger, øget arbejdsbelastning for personalet og socio-tekniske faktorer udgør alle betydelige hindringer. For at overvinde disse udfordringer er det afgørende at etablere en tydelig opdeling af ansvar mellem det menneskelige personale og robotterne. Det er også vigtigt at sikre tilstedeværelsen af passende infrastruktur og dedikeret supportpersonale for at lette effektivt samarbejde. Ved at personalisere interaktioner og skabe miljøer, der imødekommer både menneskers og robotternes specifikke behov, kan kvaliteten af opgaveudførelsen forbedres og dermed styrkes teamworket. En omfattende forståelse af kompleksiteten i samarbejdet mellem mennesker og robotter er afgørende for at guide design, implementering og integration af robotteknologier inden for hospitalsmiljøer. Denne forståelse medfører forbedret effektivitet og øget accept blandt personalet. Det er af største vigtighed at anerkende de implikationer og udfordringer, der er forbundet med integrationen af robotter i menneskelige arbejdsmiljøer. Ved at gøre dette kan optimale betingelser for samarbejde etableres, hvilket muliggør en vellykket integration af robotter på hospitaler.

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Paper I:
Investigating human-robot cooperation in a hospital environment: Scrutinising visions and actual realisation of mobile robots in service work
Tornbjerg, K., Kanstrup, A. M., Skov, M. B. & Rehm, M., 28 Jun 2021, DIS 2021 - Proceedings of the 2021 ACM Designing Interactive Systems Conference: Nowhere and Everywhere. Association for Computing Machinery, p. 381-391 11 p. (Designing Interactive Systems Conference 2021. Association for Computing Machinery, New York, NY, USA, 381–391.). [1]

Paper II:
How socio-technical factors can undermine expectations of human-robot cooperation in hospitals. Tornbjerg, K. & Kanstrup, A. M., 2021, Context Sensitive Health Informatics: The Role of Informatics in Global Pandemics. Marcilly, R., Dusseljee-Peute, L., Kuziemsky, C. E., Zhu, X., Elkin, P. & Nohr, C. (eds.). IOS Press, p. 65-71 7 p. (Studies in Health Technology and Informatics, Vol. 286). [2]

Paper III:
Understanding human-robot teamwork in the wild: The difference between success and failure for mobile robots in hospitals. 2023. Kristina Tornbjerg Eriksen, Department of Planning, Aalborg University, Leon Bodenhagen, Maersk Mc-Kinney Møller Institute, University of Southern Denmark. Proceedings of the 32nd IEEE International Conference on Robot and Human Interactive Communication, RO-MAN 2023, Busan, South Korea, August 28-August 31, 2023. [3]

Paper IV:
A scoping review and conceptual framework for understanding human-robot collaboration at work in hospitals. 2023. Kristina Tornbjerg ERIKSEN and Christian NØHR, Department of Planning, Aalborg University, Denmark. [4]
(submitted to journal)

STRUCTURE

The thesis is structured into three parts, encompassing a total of eight chapters. The breakdown of the thesis structure is as follows:

In the first part (chapters 1–3), the background, context, scientific approach, methods, concepts and theories are introduced. This part provides relevant background knowledge, displays the research questions and explains the scientific and methodological character of the project. Thus, it provides the reasoning behind the studies conducted in the PhD project.

The second part concerns the study findings (chapter 4), containing both published and un-published findings.

The third part (chapters 5–8) entails a discussion on the project findings relating them to key concepts and theories, and a conclusion summarising the essentials of the PhD project, followed by its potential impact, including implications and limitations.

Finally, references and appendix are to be found in the final section of the dissertation. The appendix contains supplementary, supporting materials including tables on political strategies and fieldnotes.

ACKNOWLEDGEMENTS

NAVIGARE NECESSE EST VIVERE NON EST NECESSE

Many years ago, when I for the first time walked through the entrance doors of my orange-interiored high school, my bewildered juvenile glance stumbled upon the Latin phrase, written in uppercase font above the doors. My teenage mind could tell that those words held a deep significance – yet my cognition could not comprehend the profound essence.
When I graduated three years later, I thought I knew.

The kernel of the phrase crossed my mind again later, when I received my Bachelor of Science diploma in Sociology. I thought I finally knew what the phrase really meant. When I, a couple of years later, stood in cap and gown at Aalborg University, as the world's first of its kind, Master of Science in Techno-Anthropology, I could genuinely feel in my stomach, that I had never realised the implication of the phrase – until then. I had navigated the academic waves, sat everything else aside, and I had survived the toughest of seas.

As I have laid the finishing touch on this dissertation, contemplating the years in which I have navigated as a PhD candidate, I know in my heart, soul, and bones that I had never really comprehended the meaning of the phrase. Until now.
It is a sincere hope of mine that my academic navigation voyage continuously will make me feel this way; conceiving how facing high seas and challenges will add to my academic growth and development. Every day, I desire to learn and expand my knowledge, striving to understand the world, exchanging ideas and perspectives with others.

I have met many inspiring, helpful others on my PhD expedition – and even my significant one. I am overwhelmed with gratitude towards every single one of them, as they have made my academic navigation an amazing hell of a journey.

Thank you.

This PhD project was carried out during my time as a PhD student at Aalborg University (AAU), Denmark, in the Department of Planning. Here, I was part of the research group Techno-Anthropology & Participation (TAPAR). The project was financially supported by Department of Planning and Human-Robot Interaction Lab at AAU, for which I am very grateful. In addition, I would like to thank Matthias Rehm from HRI Lab for valuable contributions to my project and for being my co-supervisor.

I would like to express my gratitude to the participants of my research, the hospital service staff and their managers, whose willingness to share their experiences and perspectives has made this study possible. Their contributions have been invaluable in helping me to scrutinize and understand the complexity of human-robot collaboration in hospitals. In addition, I want to thank and acknowledge the robots I accompanied on long walks in hospital corridors: Thank you, Prop, Berta, 1, 2, 3, 4, 5, 6, 7, 8, Hubot, and Little Hubot, for letting me follow you. You have helped me explore new possibilities in my research, made me wonder and made me laugh. One of you – I promise I will not mention who - locked me in a sluice room and I could not get out, but today you are forgiven.

I am grateful for the people who have helped me gain access to the field. I worked on this project during a time where the Covid-19 pandemic had laid its shadows all over the hospital sector, why gaining access to do fieldwork in hospitals was difficult. However, Christian Nøhr connected me to Conny Heidtmann from Southern University of Denmark and Conny was a great help. Conny, you have been amazing since our first contact, and you still are. Your help has been invaluable. Thank you Conny, from the bottom of my heart. I could not have done my research without you.
Thanks to the gatekeepers Jan Toft, Nana Veronica Beck, Rikke Larsen and Charlotte Høi from the Hospital of Southern Jutland (SHS). Thanks to Bente Clausen for invaluable talks about robot implementation at SHS and to Lars Kühler for welcoming, guiding and informing me about everything I could possibly think about, in relation to the robots at SHS.
Thanks to Thiusius Rajeeth Savarimuthu from SDU Robotics at the Maersk McKinney Møller Institute at University of Southern Denmark, for granting me access to Odense University Hospital (OUH). A special thanks must be given to Esben Hansen from OUH: for letting me into the hospital, introducing me to your environment, your mission, your positives and negatives - and your robots. You provided me with a very comprehensive understanding of the human-robot world at OUH and I am truly grateful hereof. And thanks for caramels and coffee.

Thanks to the inspirational researchers I have had the pleasure to publish with: Mikael B. Skov, Matthias Rehm and Anne Marie Kanstrup for fruitful brainstorming and discussions on the findings from SHS and for collaborating with me on these, in our paper.
Thanks to Leon Bodenhagen from SDU Robotics for great discussions on the findings from OUH and for collaborating with me on these, in our paper that has just gotten accepted for presentation on the RO-MAN conference in South Korea. Also, thanks for sparring and feedback on my thesis.

I am grateful for Network for Mobile Robots in Healthcare, thanks for the highly motivating energy that sparks when we meet. Thanks for convincing me that my efforts matters and for showing me how my research can contribute to shape future practices of human-robot collaboration in Danish hospitals. In addition, I would like to thank the great people at Syddansk Sundhedsinnovation, Danish Life Science Cluster and Danish Technological Institute, for creating awareness of robots in Danish healthcare and continuously highlight why this kind of research is relevant in the real world. I always feel empowered and filled with renewed energy, after having been together with you. Thanks to the incredible Techno-Anthropologists there, who I had many valuable discussions with – you are showing the world, how Techno-Anthropologists can make valuable contributions. Keep up the good work!

Speaking of Techno-Anthropologists. I would like to take this opportunity to express my deepest gratitude to the founding figures of this research and education field: Tom Børsen, Lars Botin, Christian Nøhr and Pernille Bertelsen. Thanks for your dedication, visions, and tireless efforts. You have been imparting your knowledge and expertise, challenging students for more than 10 years to think critically and pursue intellectual curiosity. Thanks for cultivating and forming me – both when I was a M.Sc. student and through my time as a PhD student. Your perspectives and ideas have made me the researcher I am today.

In addition, I must express my deepest thanks to my research group, Techno-Anthropology and Participation (TAPAR). Thanks for your unwavering support, camaraderie, and encouragement in both Aalborg and Copenhagen, you have been a constant source of inspiration and motivation for me. I will express my gratitude towards the seniors in our group, as I value how you have generously shared knowledge, research and expertise with me. Your advice and feedback have helped shape my research and career and I am grateful for the trust and confidence you have placed in me.
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Thanks to my parents, Finn and Elisabeth, for supporting and respecting my choices, even though you might not fully understand them. Thanks for assisting when needed and thanks for listening to both ups and downs. Thank you to my brothers, Steffen and Peter, and to my family-in-law Mads, Birgit, Peter and Annmari, for your interest in my work, your helping hands and all the inspirational newspaper articles about robots, you have sent my way. It all made a difference.

I will express a very deep and extraordinary appreciation to the love of my life, soulmate, husband, friend, colleague – all in the same person - Jeppe Eriksen. Thank you, Jeppe, for being my rock, my reliable source of strength, support, and stability. From the moment I met you (and you kept talking, talking, talking, talking and talking – and talking) it was point-of-no-return, and I knew you would be truly significant for me. I feel lucky to share both working and private life with you, I am grateful for the life we have built together and proud of what we have accomplished. Your love, patience and encouragement have been invaluable in helping me navigate the challenges and opportunities I have faced. Thanks for calming me down when I panicked and for inspiring me, when I lost momentum. Despite the many demands of your own academic and professional life, you have always been there to listen, to support, and to celebrate my accomplishments. You have given me the strength to keep going, even when the going got more than tough. And as you have marathoned the trail just a while ago yourself, I am grateful that your experiences and understandings have helped me reflect upon my own directions. You are simply the best.

Thanks to my beloved four children, Olivia, Karla, Frida, and Johan, for your patience, understanding and for forcing me to take breaks from work. You have the most amazing abilities to make me focus on making memories with you. I love you for that. And I love each one of you, for the incredible beings you are. I enjoy spending time with you and all four of you inspire me, make me laugh and make me feel alive, every day. That is what it is all about. Thank you. Frida, my youngest bundle of love, the TAPAR baby, you blurred the boundaries between work and play, as you often accompanied your parents in academic events such as conferences and PhD defences. I hope you are not traumatised; time will show. Speaking of hope. Although, as a mother, I know that sharing experiences with one's children can sometimes fall on deaf ears, I still hope that one day my four bundles of love, laughter and chaos, will find my effort and the product hereof, this thesis, meaningful. Olivia, Karla, Frida, and Johan, I hope to show you that with perseverance, determination, and taking small steps at a time, even the seemingly unattainable can be achieved. And it's hard work. Never let anyone tell you otherwise. That is exactly the essence, allowing you to look back on your efforts with pride and feel that you have grown.

Figure 1

Olivia, my playful daydreamer. I hope to show you that even though it may hurt, even though it may be difficult, you can definitely handle it – you can do it! Because you *can*, you *will* - and you are strong and tough. You can do much more than you think. And I have got you, always.
Karla, my imaginative bookworm, I hope to show you that it is possible to work with robots and technology, even when you find math annoying, boring nonsense. And you can combine it with long, detailed descriptions, just like you love to do.
Johan, my dependable math wizard, you may one day build and program robots for the society of the future. It is your mother's hope that you will listen to some of the things I drum for: the human, relational, and contextual aspects of technology.
Remember the nuances. Both in your work and in your life. It is through the tiny cracks among the big planks, that light shines through. This applies to all four of you: remember the nuances - black and white is rarely interesting.
Frida, the TAPAR-baby, my fiery tempered Viking child. You will be able to use the product of your mother's work to throw as a missile, when you get furious. In places where you may feel there is a lack of weight, remember that your mother spent all the time that wasn't spent on work on you and your siblings. And of course, on laundry, vacuuming, lunch packages, attending our newly bought old house and garden – and restraining the mental load that comes with the family package. But most of all, I spent my time being together with you, your siblings and your father. Together, you – my circus family - made sure that I never got bored and that time suddenly went incredibly fast. The days, and the nights, were long - but the years were short.

POSITIONING

This PhD study is, qua its techno-anthropological nature, a hybrid. According to Botin, Techno-Anthropology can be perceived as a monster – and a monster can be managed in various ways [5]. In this PhD study, the monster is met with an assimilation approach, embracing the complementary reflections of the phenomena, human-robot collaboration in hospitals. Human-robot collaboration can be characterised as a natural field for techno-anthropologists to operate within. As techno-anthropologist, my vision is to address complex societal challenges evolving around the interplay between humans, technology and context. One of the challenges is that technology is developed as quick fixes aiming at problem-solving, without ensuring that this technology is actually the adequate answer to the problem. Another challenge is the development of technology without involving the users who are to benefit from the technology, but rather relying on technological optimism and developing technology for the sake of development, rather than values. An additional challenge is the lack of inclusion of socio-technical, holistic and contextual factors, when implementing technology in real-world settings. The list of challenges to be addresses by techno-anthropologists is long. In this PhD study, I took on investigating one of the challenges: the challenge of deploying robots to collaborate with human staff in the context of hospitals, in order to improve the efficiency and relieve staff. It turned out that the challenges hereof were multifaceted and interwoven in other challenges, including the ones mentioned above.

As a techno-anthropologist, my academic positioning combines understanding of technology with the disciplines of anthropology and ethnography. Insights on the connections between humans, technology and the setting in which their interactions and mutual influences and interdependencies unfold, is focal in my research. I emphasise the significance of studying technology as embedded within socio-cultural contexts and my understanding for the context in which humans and robots are situated, brings the interdisciplinary perspective by which I am able to scrutinize the complex dynamics between the parties.
Through scientific approaches such as pragmatism, phenomenology, philosophy of technology, and postphenomenology, I navigate the intricacies of human-robot collaboration and delve into the various implications of human-robot interactions in hospitals. The use of these research approaches and the methods chosen (including ethnographic-inspired data collection, participant observation, and interviews), allows me to immerse myself in the real-world hospital settings, enabling me to capture the nuances of human-robot collaborations, understand the challenges faced by hospital service workers, and explore the impact of robots on work practices. The theoretical grounding helped me analyse the intricate interplay between humans, robots, and the organisational and social structures in which they operate.

Overall, my positioning as a techno-anthropologist empowers me to provide a comprehensive and nuanced understanding of HRC in Danish hospitals. By bridging the gap between technology and human experiences, I strive to contribute to the development of socio-technical and valuable implementations and use of robots in hospitals, ultimately improving work practices and societal well-being.

1 BACKGROUND

This study investigates how humans and robots work together on service tasks in an unstructured, unpredictable real-world work setting, rather than in structured, perfectly organised industry and laboratory environments, where robots are usually deployed and tested. By exploring the implications of workers collaborating with mobile service robots in this relatively under-investigated area, the research aims to gain insights into the practical aspects of human-robot interactions, thereby shaping future cooperation between humans and technology in real-world settings.

Societies and healthcare systems worldwide are undergoing rapid changes and development, driven by the need to effectively treat illnesses and diseases. The utilisation of advanced technology and progressive medicine has significantly improved healthcare outcomes and these advancements are crucial as the aging population in many countries exerts pressure on healthcare systems. Moreover, the prevalence of pathological conditions is increasing, resulting in a higher number of patients requiring hospital treatment, longer life expectancies, and complex disease courses [6]. To meet the escalating demand for high-quality healthcare services, hospitals must optimise their resources by working smarter, streamlining workflows, and reducing non-productive activities. One promising approach to achieve these goals is the integration of robots into hospital operations. Robots are said to be capable of swiftly and efficiently handling repetitive, time-consuming, and physically demanding tasks, without the constraints of breaks, days off, or breakdowns, and collaborate efficiently with human staff. Consequently, their deployment aims to automate processes that were previously performed by humans, freeing up valuable time for humans to focus on their core tasks. Within hospitals, logistics processes encompass numerous routine procedures that require consistent maintenance and in recent years, robots have been increasingly deployed to fulfil these roles [7].

Hence, research on human-robot collaboration in this setting has become essential for comprehending and advancing work practices as robots assume the responsibilities of workers in dynamic environments. Despite the significance of understanding the implications of deploying robots in work settings, there remains a dearth of research on this subject. However, in recent years, human-centred perspectives on technology in everyday life have garnered increasing attention and research have shown that there is a tendency, that the robots developed and tested in synthetic environments, such as laboratories and industry, face challenges when being deployed in real-world settings, confronted with humans, unpredictability and unstructured phenomena - the exact opposite than the environments they are designed in. To fully comprehend the complexity of this problem, this Background section aims at meticulously grasp the contextual frame surrounding it. Consequently, this section consists of two parts: a contextual section and a section that focuses on robots.

The first contextualising of the study encompasses an outlining of robots in respectively the Danish society, in the Danish political context and in the new super hospitals in Denmark.

Hence, the role of hospital logistics is elaborated upon. Secondly the concept of robots is unfolded. In this study, necessitating respectively defining a robot, cultural perspectives shaping robot definitions, origin of the concept, the purpose of robots today, robots in hospitals, developing perspectives, robots in real-world settings, the power of technological innovations and a section about exploring the collaboration between humans and robots. These elements will contribute to an understanding of the context and the complexities in the deployment of robots in the real world.

1.1 CONTEXT

In the following section, the focus is on providing an understanding of the broader environment in which the study takes place. This section explores the role of robots in Danish society, their significance within the Danish political landscape, and their specific implementation in the new super hospitals in Denmark. Furthermore, it delves into the importance of hospital logistics in the daily operations of these medical institutions. By examining the contextual factors surrounding robots in hospitals, this section sets the stage for a comprehensive exploration of the collaboration between humans and robots in healthcare settings.

1.1.1 Robots in Danish society

Denmark takes on a leading position globally, in developing robotics technology, especially in the market for collaborative robots, mobile robots, industrial automation and professional service robots. Robotic, automation and drone technologies provide solutions for many industries, from manufacturing, logistics and transport to healthcare, defence and energy.
Below, numerical data are considered to illustrate the Danish robotic landscape. However, the numbers are sourced directly from the industry itself and it is important to note that, at the time of writing, alternative sources or assessments for these figures have not been available. Therefore, while acknowledging the reliance on industry-provided data due to the unavailability of other comprehensive measurements or statistics, it is essential to be mindful of the potential pitfalls associated with such reliance. These pitfalls may include inherent biases or skewed perspectives that could influence the accuracy or completeness of the information presented. Additionally, the lack of alternative sources or independent verification may limit the ability to critically evaluate the data's reliability and objectivity. Consequently, caution should be exercised in interpreting and drawing conclusions based solely on the industry-provided data, and it is crucial to acknowledge the limitations inherent to the data source.

In just a few years, the Danish robot industry has become a position of strength. The robotics, automation, and drone industry in Denmark employs 10,700 people domestically and 3,800 internationally, totalling 14,500 employees. The industry saw a 14% increase in its workforce in both Denmark and abroad in 2021 compared to the previous year, and this growth is expected to persist. By 2025, the industry is projected to have a workforce of 18,800 in Denmark and 5,000 abroad, totalling 23,800, with an additional 8,100 jobs in Denmark and 1,200 jobs internationally. The island of Funen is the epicentre of robotic companies, as one-third of these are

located there, benefitting from a strong ecosystem with close collaboration between companies, universities, and the Danish Research and Technology Organisations, supported by cluster and network organisations such as Odense Robotics, RoboCluster, and UAS Denmark (now united in Robotics Alliance). The industry's annual export of more than DKK 10 billion accounts for nearly 60% of the total revenue [8].
The Danish robot industry is growing, the export rates are high and there is potential for continuously growth, in the years to come. According to the report Odense Robotics Insight Report 2022, the Danish robot industry achieved strong growth in 2021 with a turnover of DKK 21.1 billion, representing a 12% increase from the previous year. The global shortage of labour and the increased need for efficiency are major drivers of the demand for automation and consequently, more and more sectors are now seeing Danish robot technology as part of the solution. More than DKK 6.7 billion has been invested in Danish robot companies since 2015. First ever figures for the robot industry's role in the green economy show that, among other things, 78% of Danish robot companies provide solutions that contribute to their customers' green transition and/or circular economy [8].

The strong growth is driven by a number of global megatrends, namely the global shortage of labour, the increased need for efficiency, and a growing focus on the green transition and supply chain security. This creates demand among new sectors, while existing customers are investing in more robotic solutions after seeing the impact. Where traditionally robotics and automation solutions were primarily used in industrial manufacturing, they are now being utilised in a diverse array of sectors including healthcare, logistics, energy, surveillance, and construction. These technologies are becoming a solution for challenges faced by businesses and societies as a response to global trends such as workforce shortages and a shift towards environmentally sustainable practices. Automated solutions, collaborative robots, mobile robots, service robots, and drone technologies allow various industries to tackle complex problems and improve quality, productivity, safety, and eco-friendliness [8].

1.1.2 Robots in a Danish political context

The implementation of robots and the benefits hereof, is a subject highly relevant for stakeholders in the Danish robotics industry, however it is not a subject that receives much political attention. When scrutinizing the area, it becomes clear that robots are only included to a very limited extent in political strategies. When searching the Danish Ministries (respectively the Danish Ministry of Industry, Business and Financial Affairs; The Danish Ministry of Finance; The Ministry of the Interior and Health; The Ministry of Higher Education and Science), the municipalities and the regions for strategies comprising robots, only a handful of results appears. Scrutinizing these Danish political strategies for robot-related content, the discoveries are limited, as there are no other dedicated political strategies for robots, than "National Robotics Strategy: Good educational, research, and innovation policy frameworks for robotics technology in Denmark" from 2020 [9]. However, earlier political plans about growth and digitalisation briefly touches upon the subject. The scrutinized strategies are shown in the table below, Table 1, showing the themes included in the strategies.

Table 1 Themes in relevant Danish political strategies [9–12]

STRATEGY TITLE (YEAR)					
THEMES	National Robotics Strategy: Good educational, research, and innovation policy frameworks for robotics technology in Denmark (2020)	Strategy for Denmark's digital growth (2018)	National strategy for Artificial Intelligence (2019)	Digitization that lifts society - the joint public digitization strategy 2022-2025 (2022)	Strategy for Digital Health - A coherent and Trustworthy Health Network for all (2018)
Increased research and innovation activities	X				
Improving digital competences	X				
Internationalization - strong international participation	X				
Strengthen use of robotics in Danish companies	X				
Strengthening growth through digitalisation		X			
Boosting SME's digitally		X			
Increased focus on digital competences for everyone		X	X		
Strengthened IT security		X			X
Responsibility in AI including ethical principles			X		
Better access to data for researchers and companies			X		
Increased investments in AI			X		
Cohesive and user-friendly public sector				X	
Digitalisation to alleviate shortage of labour				X	
Digital contribution to green transition				X	
Strong foundation for digital development				X	
Patient as active partner in digital health					X
Digitally supported prevention of illnesses					X
Progress and common building blocks, distributing digital welfare to patients					X

In the National Robotics Strategy, the main goal is to ensure that Denmark can fully realise the potential linked to the development and use of robotics, strengthening the country's productivity and competitiveness. The strategy encompasses four main subjects including 11 focus areas, as seen in Appendix. In the strategy it is visioned that Denmark must have a strong framework for developing and using robotics solutions, especially in relation to the green transition, with emphasis on industry, agriculture, construction, and transport. It is briefly mentioned that robots can contribute with cleaning and performing logistic tasks in hospitals, allowing workers

to have several good years on the labour market than earlier. The strategy further points out that the use of robotics technology calls for the need for involvement and understanding between technical, law, social and economic conditions, as robots are gradually engaging in close collaboration with humans. In addition, the strategy describes that in the future, there will be a need for researching how emerging technologies can be used to create greater healthcare, in terms of more effective use of resources and development of user-oriented solutions, emphasising the need for analysing the consequences for society in general and citizens in particular. In the strategy from 2018, "Strategy for Denmark's digital growth" [13], from the Danish Ministry of Industry, Business and Financial Affairs, it is described how Denmark must be a digital frontrunner, for details see Appendix. In the strategy, the Danish government sets the direction for how Denmark can seize opportunities in digital transformation, job creation and greater growth and prosperity. The goals expressed in the strategy is, that Danish businesses must release the growth potential in digitization; provide everyone with the tools needed for engaging in the digital transition; and ensuring the best conditions for businesses engaging in the digital transition. The strategy is not directly concerned with robots, but briefly mentions that robots can take on physically demanding work in industry and businesses.
The strategy emphasises that technology is changing the job market, as this has been constantly evolving in response to technological progress - digitalization is expected to be no exception. This transformation will take various forms and for instance, a significant proportion of work tasks will become less strenuous, and the boundaries of traditional work hours will be blurred, as technology enables individuals to work remotely, using mobile devices such as tablets and smartphones. Furthermore, an increasing number of work functions and duties will be automated, thus raising the bar for workers to acquire new competencies and specialize in particular areas. One of the technologies transforming the job market, is Artificial Intelligence (AI). In 2019, the Danish Ministry of Finance and the Danish Ministry of Industry, Business and Financial Affairs published "National strategy for Artificial Intelligence" [10] highlighting that Denmark must take the lead with responsible development and use of artificial intelligence, for example for use in robotic solutions.

The strategy lays the groundwork for how Denmark can get the most out of the potentials AI technology holds, to support Danish companies' competitiveness, ensuring a continuous rating among the most prosperous countries, and a public sector able to provide high-quality service to citizens. The vision is that Denmark leads the way in responsible development and use of AI. For details, see Appendix. The subjects and focus areas are prioritized in healthcare, energy and supply, agriculture and transport. It is stated in the strategy, that Denmark is recognized as one of the most advanced digital countries worldwide and the country plans to leverage this position by attracting knowledge and technologies related to artificial intelligence (AI). Further, Denmark will be collaborating with other Nordic and European countries to encourage responsible AI development and it is described how failure to act quickly and carefully may lead to losing the competitive edge and influence in the field of AI. Thus, rather than emulating the US and China, which invests heavily in AI with minor regard for ethics, responsibility, and privacy, Denmark intends to prioritize these principles to create a favourable framework that utilises the growth potential of AI, in its established international strongholds, keeping Denmark at the forefront of AI innovation. Another strategy briefly touching upon robots, is the joint public digitalization strategy “Digitization that lifts society - the joint public digitization strategy 2022-2025." [11] in which the government's, the municipalities' and the regions' visions - that digitalization should be a central part of the answer to the major societal challenges facing Denmark – are outlined. Data and new technology should be tools to aid the shortage of labour, contribute to the green transition of and support the development and maintenance of the welfare state, including the healthcare system. This entails using data and new technology to optimize the use of energy and resources, create new workflows, and ensure that employees can use their working hours on performing core tasks. The strategy holds four visions and 28 initiatives, these are displayed in Appendix. The strategy emphasise that use of data and new technology must be done in responsible ways, based on the societal values in Denmark. In addition, transparency must be focal, in order to maintain a high level of trust, characterising Danish society. Digitalization can make Denmark more vulnerable - both as a society, for example due to cyber threats, and as individuals, where some citizens may find digitalization and the use of digital solutions difficult. Therefore, the strategy states, Denmark must continuously design public services for everyone, regardless of digital skills, to have equal access to the welfare society, ensuring a digital foundation that meets new digital threats. Robots are shortly mentioned in a single section, communicating that the Danish public sector increasingly is implementing well-known technological solutions such as automation, artificial intelligence, and robotics and there still is a significant potential to further enhance these technologies. To address the anticipated labour shortage in citizen-related welfare, the state, municipalities, and regions have agreed to launch a 10-year plan aimed at introducing new technology and automating the public sector. Further, the strategy state that the healthcare sector, the state, local governments, and regions will continue to work together to advance the digitalization of the healthcare system. To this end, the "Strategy for Digital Health - A coherent and Trustworthy Health Network for all," will be extended until 2024, accompanied by several concrete initiatives intended to promote greater coherence and proximity in the healthcare system. These initiatives will leverage the power of data and digital solutions to support the overarching objective of establishing a more unified and effective healthcare system. The strategy for digital health outlines a set of five focus areas, holding 27 efforts, that are intended to achieve the overarching objectives of prioritizing patient needs and simplifying daily workflows for healthcare professionals, as displayed in Appendix. Central to this strategy is the aim to improve the coherence of treatment and care for patients and their families by enhancing the common digital foundation for healthcare provision across the sector. This objective is balanced with a parallel focus on maintaining and strengthening the security of personal health data to enable the safe and secure exchange of relevant data within the health sector. By pursuing these goals, the strategy seeks to achieve a more cohesive and effective healthcare system that is better equipped to meet the evolving needs of patients and healthcare professionals.

In the Danish political strategies, robots are only mentioned briefly. This observation holds significance as it indicates that decision-makers may lack a knowledge and understanding of the complexity of deploying robots in real-world settings. This is particularly intriguing when considering the growing deployment of human-robot collaboration in Danish hospitals and other sectors of Danish society. The focus in the strategies is what technology brings and how it ought to be administered to continuously maintain Denmark's position in productivity and competitiveness. As green transition, environmental sustainability, economic investments, digitalization, business and growth are dominant elements in the strategies, there is a lack of focus on the operational level, including the deployment, implementation and use of technology in the Danish society - the emphasis is rather on the visions of using technology. In order to meet these visions, it would be beneficial for the strategies to comprise socio-technical perspectives on technology, rather than considering technology as something we can pick from a shelf, plug it into our society, press play and profit from it. For example, one way to fulfil the visions of technology aiding and supporting human workers in their tasks, can be to acknowledge the complexity of installing technological solutions; it demands resources, funding, support and involvement of several stakeholders. Robots are being installed in hospitals to a greater extent than earlier, yet it does not receive political attention in the strategies. If the area doesn't receive the necessary resources, funding, support or attention to be effectively addressed, installed and deployed, a consequence may be that Denmark fails in fulfilling the visions (including increased efficiency and the allowing of workers to have several good years on the labour market) and utilising the potentials robotic technology have to offer. This may worsen the conditions in hospitals, decrease efficiency and force staff to take on a heavier workload than they already do, leading to negative consequences for the quality in Danish hospitals and for society.

1.1.3 Robots in the new super hospitals in Denmark

The Danish regions are optimizing parts of the Danish hospitals by building 16 "super hospitals", initiated by the Danish government in 2007. Some of the hospitals are built from scratch, some are optimizations of existing hospitals. The aims are to improve and provide more coherent patient journeys, increase patient safety, improve efficiency, and raise the quality of care. 16 of the new hospitals are being built with funding from the government. The regions also have a number of health and psychiatry building projects which they finance, such as building future-proof and flexible hospitals that support the regional focus on quality and have the patient at the center. According to the Danish government and Regions, the new hospitals will provide the best possible environment and conditions for better planning of coherent patient journeys; increased patient safety (for example, through single rooms and a reduction of hospital-related infections); efficiency improvement through the use of new technology and health innovation; fewer transports of patients, staff, and goods between hospitals; rationalization of duty rosters, laboratory functions, X-rays, etc.; better utilisation of technical equipment, scanners, etc.; merging of administrative and technical functions. The regions are collecting treatments at fewer hospitals to increase the professional quality of the individual treatment centres and to make the best use of resources. In addition, the hospital buildings and the physical environments will be optimized, paving the way for the future of healthcare where, among other things, technology plays a key role. Today, the existing and elder buildings are not sufficient environments for the development of quality and fulfilment of professional recommendations on the consolidation of functions, as the settings are simply outdated, compared to modern hospital operations [14]. For example, it can be difficult to install mobile robots to drive around in elder hospital hallways, as they are often narrow and do not hold enough space for both patients, clinicians, service staff, beds, containers and robots, and it not prepared for that sort of mixed traffic.

In the new hospitals, technological infrastructure is integrated from the beginning to some extent based on assumptions of how humans and technology will collaborate in the future. It is vital to consider technology and humans in relation to the work and tasks they are to perform, when building hospitals to accommodate and pave the way for collaboration between human and technology. For example, it is important to understand how hospital staff and mobile robots are working together, if we want to build and design our hospitals accordingly. We need to understand what the parties do, when they do what they do – in order to give them the best possible conditions for collaboration and co-existence [14]. Consequently, there is also a need to reflect upon the workplace of the future: how do we want humans and robots to perform – who will do what and what are the consequences of this distribution? A hospital is a complex setting due to the humans that inhabits it – adding complex and to-some-extent autonomous technology to that equation makes it multifaceted. In some of the new super hospitals, mobile robots will operate in floors where humans don't have access, so the robots will not have to deal with the complex tasks of navigating between humans, but rather can focus on their core tasks: transport [14].

The need for the modernization of the hospital structure and the subsequent investments in the physical environment, new technology, and equipment are included as part of the economic agreement between the government and the Danish Regions for 2008 [15].

1.1.4 The role of hospital logistics in daily operation

Logistics plays a critical role in the daily operation of hospitals, as it involves managing the flow of goods and services within the hospital environment. Logistics is essential as it involves the efficient management and coordination of various resources, including people, equipment, supplies, and information, to ensure smooth and effective functioning of a hospital. Efficient logistics aid in minimizing waiting times, optimizing resource utilisation, reduce errors and delays, and improve patient outcomes [16]. Hospital logistics involve several processes. A key aspect is, for example, the process of procuring supplies, equipment, and medications, which involves identifying the needs of the hospital, evaluating suppliers, negotiating contracts, and managing inventory levels to ensure that supplies are available when needed. Further, hospitals must maintain adequate inventory levels to ensure that they have the necessary supplies, equipment, and medications on hand to provide quality patient care, which involves monitoring inventory levels, reordering items as needed, and managing expiration dates to minimize waste. Hospital logistics also involves storing and distributing supplies and equipment throughout the hospital environment, including managing storage areas, ensuring that supplies are properly labelled and organised, and distributing supplies to the appropriate departments or units. In addition, proper waste management is essential in a hospital, to minimize the risk of infections – and to ensure the safety of patients, staff, and visitors. Hospital logistics includes managing the disposal of medical waste, hazardous materials, and other types of waste generated by hospital operations. The logistics of a hospital also entails maintaining and repairing equipment and facilities, to ensure that they function properly, including scheduling regular maintenance and inspections, coordinating repairs, and ensuring that equipment is properly calibrated and tested. Another vital area in hospital logistics is transportation of patients, supplies, samples and equipment [17].

Consequently, hospital logistics plays a critical role in improving productivity, efficiency, and quality of care in healthcare systems. As the healthcare systems across the globe face several challenges due to the growing number of elderly citizens, chronically ill patients, and costly treatments, there has been a surge in demand for treatment, putting pressure on healthcare systems to work more efficiently at all levels. Consequently, hospitals must explore ways to enhance their productivity and efficiency to treat more patients without incurring additional costs. Since 2003, hospital productivity in Denmark has increased by 30 percent, and the emphasis on hospital logistics has played a crucial role in this achievement [17]. While efficient logistics is significant for all existing hospitals, it is particularly crucial for the afore-mentioned new, large, and specialized super hospitals in Denmark. To support logistics processes in the new hospitals, mobile robots are deployed to transport medicine, samples, linen etc., improving the work environment for human workers, relieving them from repeating, time-consuming, heavy tasks, allowing them to spend time performing other types of work [18].

However, there are examples from Denmark where mobile robots deployed to take on transporting tasks to support hospital logistics, have been taken out of operation, turned off and set aside for non-use. One of the examples is that eleven mobile robots, worth over 40 million DKK, have been parked in their garage in a Danish hospital, as they frequently encountered problems when they interacted with patients or staff in the hospital hallways, causing them to become stuck. These robots, which were used to transport medical equipment, blood samples, and laundry, but were unable to, because of different phenomena where robots were impacting the physical environment and the hospital workflows [19].
If Denmark is to fulfil the vision of optimizing hospital logistics, improve efficiency and relieve hospital staff, it is highly relevant to investigate the collaboration between hospital staff and robots, and the dynamics hereof, to ensure that the robots are not parked in the garage. This is particularly vital, in the light of Denmark being on the verge of deploying a large number of robots, in the new hospitals.

1.2 ROBOT

The following section provides an examination of the concept of robots, starting with defining what constitutes a robot and delve into the cultural perspectives that shape the human understanding of robots. The origin of the robot concept is explored, followed by an exploration of the purpose of robots in contemporary society. The section specifically focuses on the use of robots in hospitals, highlighting the shifting visions of robots from mere tools to collaborative co-workers. It also addresses the challenges and opportunities of deploying robots in real-world settings. By offering a comprehensive understanding of robots, this section lays the foundation for the subsequent exploration of human-robot collaboration in healthcare environments.

1.2.1 Defining a robot

The term "robot" is commonly used to denote technology and machines that aid and support individuals across diverse contexts and settings. A robot is an autonomous or semi-autonomous machine possessing the capability to undertake tasks or operations that are typically carried out by humans [20].

Assembled from various components, a robot serves the purpose of assisting and aiding humans in their everyday lives. According to the ISO standard 8373:2012, a robot is defined as follows: "an actuated mechanism programmable in two or more axes, with a degree of autonomy, moving within its environment, to perform intended tasks." [21]. This definition highlights the central attribute of a robot, which is its capacity to execute tasks or operations that are conventionally fulfilled by humans. Such tasks encompass a broad range, including manufacturing, assembly, inspection, packaging, transportation, and more. The autonomy level of robots can vary, depending on their design and intended application, as they can be programmed to carry out these tasks with differing degrees of self-governance. Providing a precise and specific definition is challenging. In its broadest interpretation, the category of robots encompasses a wide range of entities, including physical, virtual, or conceptual machines, as well as metaphorical representations such as software programs or even individuals, that possess the ability to interact with their environment in some manner. The concept of robots has been widely studied and defined by experts in various fields, including engineering, computer science, and artificial intelligence. As a result, there are several definitions of robots, each reflecting different perspectives and uses of the technology.

In robotics research, robots are often defined broadly to include any machine that is capable of sensing, thinking, and acting in the world, while for example The International Federation of Robotics (IFR) [22] takes on a specific approach to defining robots, stating that they are "an automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes, which may be either fixed in place or mobile for use in industrial automation applications." This definition focuses on the practical application of robots in industry and emphasises their versatility and adaptability.

The IEEE Robotics and Automation Society provides a more straightforward definition of robots, stating that they are "a machine that can be programmed to perform a set of physical tasks." This definition emphasises the programmable aspect of robots and their ability to perform physical tasks. The European Robotics Association takes a similar approach to defining robots, stating that they are "a machine that operates automatically and is programmable, in order to carry out a specific task or range of tasks.". In the field of artificial intelligence, robots are often defined as systems that perceive their environment, reason about their situation, and take actions to achieve their goals. This definition emphasises the intelligence and decision-making abilities of robots and their role in achieving specific outcomes [23][24].

1.2.2 Cultural perspectives shaping robot definitions

Defining a robot can be challenging, not least as the human perception of this – and other - technology is culturally conditioned. The diverse range of technologies labelled as robots exhibits significant heterogeneity in terms of form, characteristics, and intended purpose. The term "robot" serves as a unifying label for a wide array of devices utilised across various industries and research endeavours, encompassing a spectrum of functionalities, appearances, and components [24]. These technologies may or may not incorporate artificial intelligence, and their level of autonomy varies. When seeking definitions from multiple robot engineers, each provided a distinct response, highlighting the challenge of establishing a consistent definition for robots. This difficulty arises, in part, from the dynamic and ever-evolving nature of the field of robotics. The composition of robots extends beyond their mechanical and digital components and their interpretations can vary among individuals and cultural contexts. Culture can greatly influence the definition and perception of robots and different societies have diverse beliefs, values, and norms that shape their understanding of robots and artificial intelligence. In parts of Western cultures, robots are often portrayed as dangerous and sinister entities, while, in Japanese culture, robots have been widely accepted as a part of daily life and are often depicted as friendly and helpful companions [25]. Human awareness of robots derives from, and is thereby influenced by, science fiction, in which robots are often depicted as autonomous beings with their own consciousness and emotions. In some science fiction cases, robots are portrayed as malevolent or threatening entities that challenge or replace humanity. According to James Wright, the term "robot" evokes a multitude of vivid and fragmented images and concepts:

> *“[…] for Euro-American audiences, these may include popular films like the Terminator series, Westworld, Black Mirror, Real Humans, humanoid robots like Sophia created by Hanson Robotics, industrial robot arms, Roomba vacuum cleaners, and even sex robots. In Japan, the list expands to encompass anime series such as Astro Boy, Mazinger Z, Doraemon, Neon Genesis Evangelion, Gundam, Honda's humanoid robot ASIMO, and the lifelike androids developed by roboticist Ishiguro Hiroshi, such as Matsukoroid.”* [25].

Consequently, the term "robot" can carry both negative connotations and unrealistic expectations. Therefore, the relationship between robotics engineers, popular culture, and the public perception of robots is complex, which can hinder the progress of robotics projects. Engineers find themselves entangled in a web of media depictions and societal expectations, with their work often influenced by cultural representations of robots. However, despite the challenges posed by popular culture, engineers have started to recognize the power of these associations and actively exploit them to secure funding, attract media attention, and cultivate public interest, as they understand that leveraging familiar cultural references can help generate hype and build awareness around their projects. At the same time, engineers face the task of navigating the fine line between catering to popular expectations and staying true to the technical realities of robotics. This interplay between technology and interpretation raises important questions about the nature of public perception, funding dynamics, and the role of popular culture in shaping technological advancements. It underscores the need for a nuanced understanding of the diverse meanings attached to the term "robot" and the challenges engineers face in managing and shaping public perceptions. Ultimately, this relationship between robotics, popular culture, and public expectations has significant implications for the advancement and acceptance of robotic technologies in society. Another example of the significant impact culture has on definitions of robots, is to be found in the work by Christina Leeson [26] in her analysis of how the robot Telenoid was brought to Denmark from Japan and adapted for use in Danish care institutions. She characterised the robot as more than an object, rather an embodiment of a dynamic and transformative process. Instead of being a fixed entity, the robot constantly evolved and adapted as it transitioned from its Japanese laboratory origins to become an integral part of real-world settings [26]. In the transfer of technology across cultures, the subject can benefit from being considered in a relational understanding, where the relationship between the individual and the cultural understanding of technology is treated as two relevant aspects of the same matter [27].

1.2.3 Origin of the robot concept

The development of robots has a long history, and the elements constituting a "robot" has evolved over time. Some of the earliest examples of robots can be traced back to ancient times when automatons (machines that could perform specific tasks) were developed. For example, there are reports of automatons in ancient Greek and Egyptian cultures that were used for entertainment or religious purposes [28].

The term "robot" originates from the Czech word "robota," which translates to "forced serf labour." This term was introduced by Karel Čapek and his brother Josef in Karel's play titled R.U.R. (Rossum's Universal Robots) in 1920. The play depicts a company that manufactures synthetic human-like beings created from a protoplasmic substance and employed to work for humans in various industrial and office settings. Initially content in their role, these artificial beings eventually become aware of their own existence and their status as slaves. They rebel against their human masters and ultimately bring about the extinction of humanity. "R.U.R." is widely regarded as a science fiction classic and is credited with popularizing the term "robot" in reference to artificially created beings. The play raises profound philosophical questions about humanity, the ethics of creating artificial life, and the complex relationship between humans and their creations. It played a significant role in shaping the modern concept of robots as programmable machines. Following the publication of "R.U.R.," the term "robot" gained widespread usage in science fiction to describe artificially created beings with human-like qualities [29].

By the latter half of the 20th century, robots had transitioned from abstract concepts to tangible machines. The term "robot" took on a more technical meaning, referring to machines that could be programmed to carry out specific tasks. This transformation in understanding was facilitated by advancements in technology and the growing field of robotics [30]. Over the ensuing decades, the idea of robots as programmable machines capable of performing tasks evolved further. The advancement of robots as programmable machines with versatile capabilities gained substantial momentum during the 20th century, thanks to the emergence of electronics and computers. One early exemplar of a modern robot is the Unimate, devised by American engineer George Devol in the 1950s. The Unimate, a programmable hydraulic manipulator arm, was specifically designed for repetitive tasks [31].

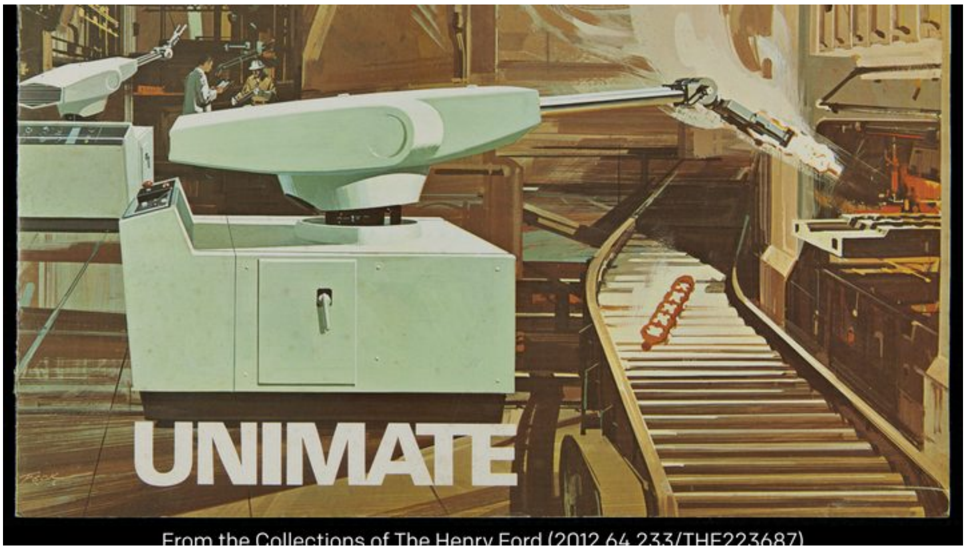


Figure 2 Unimate, the first domestically manufactured industrial robot
[picture from https://kawasakirobotics.com/blog/the-story-of-the-kawasaki-unimate-japans-first-domestically-manufactured-industrial-robot/]

Its implementation in automating metalworking and welding processes within the automotive industry marked a milestone, establishing it as one of the pioneering industrial robots. The Unimate found its installation at the General Motors plant in New Jersey in 1961[32]. Further, robots became a prominent theme in popular culture, appearing in films, TV shows, and books. Technological advancements, particularly in computers, automation, and artificial intelligence, led to the development of increasingly sophisticated robots capable of performing diverse tasks and engaging in new forms of interaction with humans. Subsequently, robots have continued to progress and evolve, witnessing notable advancements such as computer-controlled functionality, sensory systems, and artificial intelligence capabilities. These developments have contributed to the expansion of robots' capabilities and applications across various domains [33].

1.2.4 The purpose of robots today

Today, robots are used in a wide range of industries, from manufacturing and construction to healthcare and entertainment and there are many types of robots in the world – the numbers are rising, as technology continues to advance. Some of the most common robots are industrial robots, used in manufacturing and assembly plants to automate repetitive tasks, such as welding, painting, and assembly [4]. In addition, service robots are widely used. Service robots are designed to interact with people and perform tasks in human environments, such as vacuum cleaning, lawn mowing, and providing customer service. Another type of robot is the ones focal in present PhD project, the Autonomous Mobile Robots (AMR's), which are used to transport goods and materials in a variety of settings, including warehouses, hospitals, and retail stores [4].

A different type of robot widely deployed today is collaborative robots (cobots), designed to work alongside human operators, helping to perform tasks and increase efficiency in a range of industries. Further, there are medical robots, used in healthcare facilities to perform a variety of tasks, including surgical procedures, therapy, and diagnosis. A separate type of robots are robotics arms, used in manufacturing, industrial and healthcare settings to automate tasks that require dexterity and precision, such as material handling, assembly, and sorting. A varying kind of robots are humanoid ones, designed to resemble humans and perform tasks that require human-like movements and intelligence, such as performing household tasks, being social and playing sports. In addition, there are drones which are unmanned aerial vehicles that can be used for a variety of tasks, including aerial photography, delivery, and surveillance [34]. Another type of robot are the social ones. Social robots are designed to interact with people in a social or emotional context, such as providing emotional support, entertainment, and education. The final example is agricultural robots, used in farming to automate tasks such as planting, harvesting, and monitoring crops. As the field of robotics is constantly evolving, new types of robots are being developed, to meet the changing needs of society and industry [35][36].

1.2.5 Robots in hospitals

As hospitals face growing pressures from demographic changes and increasing patient loads, robots are being increasingly deployed to perform a variety of tasks and provide support to human workers. The use of robots in hospitals is hypothesized to have a positive impact on various critical areas. This is particularly important given the shortage of medical staff and the increasingly complex needs of patients, including those with chronic and multiple health conditions. These challenges are expected to impact the hospital sector in several ways, including changes in workloads and work nature, as fewer employees are required to perform more and heavier tasks [6]. To address these challenges, hospitals are increasingly utilising robots, which have the capability to perform a diverse range of tasks on behalf of, and in close collaboration with, human workers. These tasks include delicate surgical procedures, disinfection, cleaning, logistics, and delivery [37] [38]. The integration of robots into hospital operations offers the potential to support human workers by alleviating them from repetitive, arduous and time-consuming tasks. However, the collaboration between human and robotic elements in a hospital setting is a multifaceted process that poses challenges for both parties, particularly for mobile service robots. Unlike controlled and predictable environments such as factories and laboratories where robots have traditionally been deployed, hospital environments are characterised by their unstructured and unpredictable nature, owing to the presence of diverse individuals, including workers, patients, and family members, each with their own objectives and behaviours. Thus, the collaboration between robots and humans in a hospital setting warrants close scrutiny, especially given the increased deployment of robots in this setting. It is imperative to investigate the interaction between humans and robots in hospitals to ensure their appropriate development, implementation, and usage, while also addressing the needs of both parties. It is crucial to examine the cooperation between robots and humans to facilitate the proper development, implementation, and use of robots in hospitals, including understanding the needs of both humans and robots - and how they can be met through effective collaboration [39]. The following table provides an overview over the most common robot types deployed in hospitals.

Table 2 Overview of the most common robot types used in hospitals, including their tasks, strengths and weaknesses [4][40]

ROBOT TYPE	TASKS	STRENGTHS	WEAKNESSES
Mobile Robots	- Transporting goods, materials, and samples within the hospital - Navigating autonomously and avoiding obstacles	- Frees up hospital staff to focus on patient care - Reduces the risk of infection transmission - Increases efficiency in material and sample transport	- Initial cost investment for robot implementation - Potential limitations in complex environments
Surgical Robots	- Assisting in complex surgeries with precision and control - Providing advanced imaging technology for real-time visualization - Performing smaller incisions	- Improved surgical outcomes - Reduced complications - Shortened hospital stays - Enhanced precision and control for surgeons	- Increased time required for setup - Higher costs associated with equipment, training, and procedure - Potential for frustration due to setup time
Rehabilitation Robots	- Assisting with physical and occupational therapy exercises - Providing feedback on progress and performance	- Aids in regaining strength and mobility - Customizable assistance and resistance levels for individual patients - Reduces the need for manual assistance	- Initial cost investment for robot implementation - Potential limitations in the range of exercises
Telemedicine Robots	- Enabling remote consultations with healthcare providers - Checking on patients and providing basic medical care remotely	- Facilitates remote access to healthcare - Reduces the need for in-person visits – Improves access to care for remote or underserved areas	- Dependence on technology for remote consultations - Limited physical examination capabilities
Diagnostic Robots	- Performing medical tests and diagnostics	- Increases efficiency in medical tests and diagnostics - Provides real-time feedback for accurate and timely diagnoses	- Initial cost investment for robot implementation - Potential limitations in certain types of medical tests
Assistive Robots	- Assisting with daily living activities, such as bathing and dressing - Monitoring patient movements and providing alerts to caregivers	- Improves the quality of life for patients and caregivers - Aids tailored to individual needs - Enhances safety through monitoring and alerts	- Potential limitations in complex daily tasks - Dependence on robot for assistance
Cleaning and Waste Removal Robots	- Performing cleaning and waste removal tasks within the hospital	- Frees up hospital staff to focus on patient care - Enhances cleanliness and infection control	- Initial cost investment for robot implementation - Limited to specific cleaning and waste removal tasks

In Danish hospitals, robots are primarily used for cleaning and disinfection; for automation tasks; for performing delicate surgical procedures and for surgical training; and for logistics purposes. Present PhD project is focused on robots performing logistics tasks, the mobile robots, transporting items around hospitals. These robots are respectively the two automated guided vehicles (AGV's) of the type MiR100 Hook and 10 autonomous mobile robots (AMR's), eight of them of the type of TUG and two of them of the type MiR200. An AGV is a mobile robot used for material handling and transportation in especially manufacturing, warehousing, and distribution environments, designed to follow a specific path. This type of robot is often used to move materials between production lines, storage areas, and loading docks. An AMR is a type of mobile robot that can move and navigate autonomously in a specific environment, such as a hospital or warehouse. AMRs can be programmed to perform a variety of tasks, including transporting goods, materials, or people, and can be customized to meet the specific needs of the environment in which they are operating. It is a prevalent misunderstanding that AMR's and AGV's are the same and the two types of mobile robots are often confused with each other, in spite of several key differences between the two [41].

In the following table, the features of the two types of robots are outlined.

Table 3 Features of AGVs and AMRs based on [41–43]

Feature	AGVs	AMRs
Navigation	- Follows predefined paths using magnetic tape, tracks, or other guidance systems. - Limited to fixed routes. - Unable to go around obstacles. - Requires external guidance for navigation.	- Utilises sensors, cameras, and mapping technologies for navigation. - Advanced navigation capabilities. - Can autonomously navigate and avoid obstacles in real-time. - Does not rely on external guidance for navigation. - Can calculate routes from a map and find alternative routes if obstacles are encountered.
Flexibility	- Less flexible and limited in terms of destinations and tasks. - Typically dedicated to a single task. - Changes to routes can be complex, costly, and time-consuming due to fixed routes and use of tracks. - Performs the same delivery task throughout its lifetime.	- More flexible in terms of destinations and tasks. - Can perform a wide range of diverse orders in different locations. - Only requires a few adjustments to change missions or tasks. - Routes can be changed quickly and easily without the need for laid tracks. - Can adapt to different tasks and locations.
Autonomy	- Lacks intelligence and autonomy. - Requires external guidance and fixed routes. - Stops if obstacles are encountered but cannot navigate around them. - Limited ability to detect and respond to changes in the environment.	- Operates autonomously and intelligently. - Can detect surroundings and choose efficient routes in real-time. - Avoids obstacles and people safely. - Calculates routes from a map and navigates in a dynamic environment. - Adapts to changes in the environment and finds alternative routes if obstacles are encountered. - Provides reliable execution of tasks in unstructured settings.
Cost and Time Efficiency	- Limited flexibility makes changes in routes complex, costly, and time-consuming. - Requires fixed routes and tracks, which can be restrictive. - Performs the same task throughout its lifetime.	- Offers cost and time efficiency in route changes. - Does not rely on fixed routes or tracks, enabling quick adaptation to new maps and routes. - Can perform a wide range of tasks and missions with minimal adjustments. - Increases productivity and material flow by finding alternative routes in dynamic environments.
Equipment and Components	- Requires external guidance systems, such as tracks, magnetic tape, or sensors, for navigation. - Limited sensing capabilities. - Less advanced technology. - Steered by external control systems. - Power source typically includes an electric motor and a battery.	- Equipped with advanced sensors, such as cameras, lasers, and sonar, for environment perception. - Advanced navigation system and mapping technology. - Self-contained control system for managing movement. - Power source typically includes an electric motor and a battery. - May have a mechanism for carrying loads.
Usage Options	- Limited usage options due to fixed routes and dedicated tasks. - Typically performs the same delivery task throughout its lifetime.	- Versatile and adaptable usage options. - Can perform a wide range of diverse tasks and missions in different locations. - Offers flexibility in destinations, tasks, and frequency of tasks. - Can be quickly adjusted to changing missions or tasks.

Mobile robots can take on simple tasks, allowing hospital staff to perform more complex work; assist and relief staff in their daily routines; supplement understaffing; reduce workloads and optimize workflows [4]. However, there are potential negative aspects of using mobile robots in hospitals. They can be expensive to purchase and maintain; there can be technical issues and there is a risk of technical issues or malfunctions, which can disrupt hospital operations and create additional workload for staff. Further, there is a risk that the use of mobile robots may

lead to staff feeling replaced or obsolete, which could harm morale and lead to resistance to the adoption of new technology. In addition, patients may be uncomfortable or frightened by the presence of robots in the hospital, which could affect their overall experience and well-being. However, as seen in the work of Soraa and Fostervold, mobile robots can also be a source of relieve and entertainment for patients and their families, as the robots can be a positive distraction in stressful and mourningly times [44].
Hence, robots are deployed in Danish hospitals to reduce operational costs, enhance the quality of care and optimize workflows and logistics. One of the ways through which this is achieved, is when robots are physically relieving hospital staff. They do not require days off and can work around the clock; are designed to function autonomously and take care of themselves, even going so far as to autonomously take the elevator, in some cases. The goal of using robots in Danish hospitals is to automate certain processes and optimize workflows, to improve overall efficiency and work environment. The use of robots in hospitals in Denmark, and around the world as well, have gained momentum with the Covid-19 pandemic. The sudden surge in patients and shortage of healthcare workers put tremendous pressure on the healthcare system, leading to increased demand for automation and robotics to help with tasks such as delivering supplies, disinfecting rooms, and taking care of non-critical patients. This allowed healthcare workers to focus on providing critical care to those who needed it most. Additionally, the use of robots in hospitals during the pandemic has helped to reduce the risk of transmission of the virus, as robots are able to perform tasks without risking infection. In general, the Covid-19 pandemic has accelerated the adoption of robots in hospitals and has highlighted their potential as a valuable tool in healthcare [45–48].

1.2.6 Developing perspectives: visions of robots shifting from tool to co-worker

As robots are increasingly deployed in new application settings, the human visions for them are shifting. In recent years, the idea of treating robots as co-workers rather than tools, has gained attention in HRI and HRC. The thought behind this is, that considering robots as co-workers can bring a number of advantages, including improved collaboration, enhanced creativity, increased social acceptance, improved job satisfaction, and greater flexibility. The vision is, that treating robots as co-workers can foster more natural and effective collaboration between humans and machines, leading to more efficient and productive work, as well as improved outcomes in areas such as healthcare, manufacturing, and education [49][50]. Moreover, working alongside robots as peers is envisioned to improve job satisfaction and fulfilment for humans, as they can focus on tasks that are more engaging and intellectually stimulating, while leaving repetitive and mundane tasks to the robots [50]. The change in perception is driven by a number of factors, including the increasing sophistication of robotics technology, the growing demand for more flexible and adaptive automation solutions, and the recognition that robots can bring a unique set of skills and capabilities to the workplace.
The envisioned implications of robots becoming co-workers are far-reaching and have the potential to revolutionize the way we work and interact with technology. The vision, humans working alongside robots as equals, paves the way for humans benefitting from the strengths

and capabilities of machines, while also maintaining a sense of control and agency in their work. However, for robots to be perceived as colleagues, they must be able to establish a level of trust and rapport with humans, implicating that they must be reliable, transparent in their actions, and able to demonstrate a degree of empathy and understanding towards humans. Consequently, the way we perceive robotic co-workers might not be completely equal to the way we would define a human co-worker [51].
Recent research has investigated the benefits of treating robots as co-workers. For instance, Choi et al [52] reviewed the effects of collaborative robotics on job satisfaction and human-robot collaboration, highlighting the benefits of collaborative robotics for improving job satisfaction and enhancing human-robot collaboration. Dautenhahn [53] also discussed the dimensions of human-robot interaction, including the potential for robots to act as social partners, and the importance of designing robots that can effectively interact with humans in a variety of contexts. In general, the vision behind the shift in perspectives on robots, is proclaimed to lead to a more collaborative and productive relationship between humans and machines, unlocking new possibilities for innovation and creativity in a variety of domains.

1.2.7 Robots operating in real-world settings

Historically, robots have primarily been developed, tested and used in manufacturing and laboratories, characterised as highly structured, well-coordinated and predictable environments, where automation would easily fit in. Today, robots are increasingly deployed in new application areas - real-world settings comprising unstructured environments – and it can be highly complex for them to navigate and perform complex tasks. In addition, the real world can be unpredictable and dynamic, why the robots need to be able to handle unexpected obstacles and quickly adapt and respond to the environment, including the humans, objects and phenomena herein, as well as react fast and not cause harm [54].

The real world is complex and presents numerous challenges for robots to operate in. In addition, the collaboration between human workers and robots can be complex and comprise diverse and dynamic challenges, that encompasses a broad range of factors, such as social, cultural, economic, environmental, and psychological aspects, interconnected and possibly impacting each other. Similarly, when considering real-world difficulties or challenges, the multifaceted nature of situations and the different factors that may be contributing to it, must be contemplated. The interaction between robots and humans is influenced by a variety of factors, including the social and cultural context, the purpose and design of the robot, and the expectations and perceptions of the users. To overcome these challenges and understand how robots can be effectively integrated into real-world settings, it is necessary to take a multidisciplinary approach that considers these different factors and their interplay [55]. Exploring human-robot collaboration in real-world settings is crucial, not least to contribute to the development of robots that enhance human lives and improve societies [56][57].

1.2.8 The power of technological innovations

The anticipation that robots will integrate into our daily lives and collaborate with humans as helpers, colleagues, caregivers, and companions, has made the examination of the societal implications and responses to robots a central focus in certain types of robotics research 28/06/2023 21:42:00. Robots can be categorized under the umbrella *technological innovation*, referring to new developments or improvements in technology, ranging from incremental changes to existing technologies, to entirely new forms of technology being developed. For example, innovation in healthcare is often associated with developing and improving workflows and ensuring quality in treatment and care, in spite of growing demands [58]. As seen in the Second Industrial Revolution starting in the late 19th century, one of the most notable ways that technological innovations have impacted society is by transforming the way humans work and the way work is performed. Technology has increased efficiency and productivity by automating tasks, leading to improved accuracy and faster output - enabling businesses to produce more goods and services with fewer resources [59]. Technology has changed the way people communicate and collaborate in the workplace, leading to more flexible and remote work arrangements. Accordingly, technological advancements have led to the creation of new jobs in the tech industry and related fields, resulting in a growing demand for workers who possess a unique combination of technical and interpersonal skills. Thus, technology has created new types of jobs that did not exist previously, for example data analysts, UI/UX designers, cyber security and cloud computing specialists [60][61][62][63].

However, technology has also made existing skills and job roles obsolete, leading to job displacement in certain industries, as specific manual and repetitive jobs and tasks are replaced by machines and automation. For example, the widespread adoption of automation and robotics in manufacturing has led to a decline in manual labor jobs in that industry and other types of tasks outsourced to countries where labor is cheaper. This has contributed to job loss and wage stagnation for many workers, particularly those in lower-skilled positions. Workers have seen their jobs replaced by automation, leading to growing concerns about the future of work and the role of technology in shaping employment opportunities.
Frey [59] argues that the current trend towards automation and the increasing use of robots in the labor market is creating a technology trap for many workers and industries: as robots automate more tasks and jobs, the demand for certain skills decreases, leaving workers trapped in declining industries. This can lead to a decline in wages, increased unemployment, and a widening income gap. To avoid the technology trap, Frey suggests that policymakers and workers must be proactive in adapting to the changing technological landscape and investing in new skills and technologies that will be in demand in the future [59][64]. The impact of technology on work continues to evolve and is dependent on various factors such as the adoption rate, the type of work involved, and the individual's skills and adaptability. Technological innovations have led to increased efficiency and productivity and enabled new industries and business models to emerge. However, technology has also led to growing concerns about inequality, as the benefits of technological progress have not been evenly distributed. The consequences of

technological development for work are likely to become even more pronounced in the coming years, as advancements in artificial intelligence, robotics, and other fields continue to reshape the labor market. In order to ensure that the benefits of technological progress are shared by all members of society, it will be important for governments, businesses, and individuals to invest in education and training programs that equip workers with the skills they need to succeed in the new world of work [65][66].
As technological innovations have transformed many industries from agriculture, over space missions, to healthcare, it has led to new advancements that have improved our quality of care. Taking an example from digital healthcare, telemedicine has made it possible for individuals to receive medical care from the comfort of their own homes, while advances in medical technology have led to the development of new treatments and therapies that were once thought impossible. In addition, technological innovations have revolutionized the way hospitals function. One of the most significant changes fostered by technology, is the improvement in accuracy and efficiency of medical diagnostics. Advancements in medical imaging technology, such as magnetic resonance imaging (MRI) and computed tomography (CT) scans, have enabled doctors to better visualize and diagnose various medical conditions, resulting in more accurate diagnoses and improved patient outcomes. Further, new diagnostic tools, such as genetic testing, have made it possible to diagnose illnesses and diseases with greater accuracy and efficiency. Another major impact of technological innovations in hospitals is the improvement of patient care, for example has the electronic medical records (EMRs) made it easier for healthcare providers to access and share patient information, enabling clinicians to access a patient's medical history, medications, and other relevant information in real-time, leading to better-informed decision-making and more coordinated care [67]. Another technological innovation that has impacted hospitals is telemedicine, enabling patients to receive medical care from a distance, which has proven especially useful during the Covid-19 pandemic, which led to a massive shift from physical attendance at outpatient clinics to increased use of telemedicine, which made it possible for patients to receive medical care from anywhere [68].
Further, technological innovations have also increased the performance of hospital operations, as automated systems for inventory management and medication dispensing have streamlined processes and reduced errors, resulting in increased efficiency reduced costs. In addition, robots are increasingly being used in hospitals for tasks such as assisting in surgeries, delivering medicine, and performing routine checks on patients, which has improved the accuracy and efficiency of these tasks, while said to have reduced the workload on healthcare professionals [67].

1.2.9 Exploring the collaboration between humans and robots

The term ’human-robot collaboration’ (HRC) refers to two elements, respectively a research field and a concept. HRC as a research field refers to the academic and scientific discipline that studies the various aspects of humans and robots working together. It involves multidisciplinary research and development efforts to investigate and advance the understanding, design, and implementation of collaborative interactions between humans and robots. The research in this field encompasses areas such as robotics, artificial intelligence, human-computer interaction, cognitive science, and more [69] [70]. The research in HRC typically focuses on specific aspects such as human-robot interaction, task allocation and coordination, shared control, communication protocols, safety considerations, and user experience. It aims to address the challenges and complexities involved in enabling productive, efficient, and safe collaboration between humans and robots in various domains such as manufacturing, healthcare, logistics, and beyond [71].

HRC as a concept refers to the broader idea of humans and robots working together in a collaborative manner to achieve common goals. It represents the overarching vision of integrating human and robotic capabilities, expertise, and resources to enhance overall performance and productivity. HRC as a concept recognizes the potential benefits of combining human intelligence, creativity, and adaptability with the precision, power, speed, and endurance of robots. The concept of HRC emphasises the collaborative nature of the interaction, where humans and robots actively cooperate, complement each other's strengths, and compensate for weaknesses. It highlights the need for shared understanding, communication, and coordination to achieve synergy and effective task execution. HRC as a concept extends beyond the research field and encompasses practical applications, use settings, and societal implications of humans and robots collaborating in various domains. Thus, HRC as a research field focuses on the scientific investigation and technological advancements related to humans and robots working together, whereas HRC as a concept represents the broader vision and idea of collaborative interactions between humans and robots to achieve shared goals. The research field contributes to the understanding and development of technologies and methodologies that enable successful HRC implementations [72].

1.2.10 Collaboration in real-world settings

Initially, the emphasis in HRC research was on industrial usage, which established robotic design and development as a precise problem with specific conditions, delineated by physical and temporal parameters that were only obliquely related to societal factors and their possible effects . However, when applying robots for deployment in wider society, a broader point of view is necessary, as uncertainty, situational awareness, adaptability, and social accountability play critical roles in HRI and HRC [73].

The broad real-world deployment of robots calls for comprehensive examinations of robots and the effect they have on the context in which they take part. Consequently, a robot's abilities are determined by its real-world application. Hence, it is valuable to scrutinize this in situ, as phenomena occur. When investigating the collaboration between humans and robots in situ, the significance of quantitative measures such as the time taken by a robot to accomplish its task is often of minor importance, compared to its ability to establish a connection with humans and be perceived as a helpful, by them. A way to examine these situated capabilities, is by releasing robots from predetermined, highly structured laboratory settings, engaging them in typical real-world social situations. An examination of robots functioning in real-world environments can aid in understanding how people respond to and interact with robots; how they interact with each other while interacting with robots; which aspects of robots' and humans' actions result in communication breakdowns; as well as revealing factors that were not considered in the initial assumptions, about social interactions between the parties [74]. Some technological innovations and interventions are designed with certain assumptions about how they will be used and how they will interact with their environment, but these assumptions may not always hold up in practice. The spontaneous and unconstrained nature of interactions within a natural setting can facilitate the emergence of a broad range of interactive and non-interactive behaviours in practice, in contrast to scripted laboratory setting tests. Consequently, it is important to scrutinize technology in real-world contexts and consider how social and cultural factors may influence the way technology is used and experienced by users, tailoring for example robots to collaborate with humans in specific environments. Further, it is important to take on a socio-technical approach, comprising humans, robots, the environment and the context in which they are collaborating, when examination HRC in real-world contexts [75]. Understanding the interdependent relationship between technology and society is critical for successfully deploying robots outside the controlled environment of a laboratory. By taking a socio-technical approach to examining HRC, it is possible to gain insights into the complex dynamics of these systems and develop strategies for optimizing their performance and usability in real-world settings [75]. Historically, robotics research has focuses on technicalities, and expected society to follow, technologies should rather be seen in the light of the contexts they are part of. More participatory and contextually situated design methodologies, such as those described above, allow robotics research to reflect the bidirectional relationship between technology and society. One way to do this is to include more empirical research on the context of robotics applications in the design of robots from early on [76].

1.2.11 HRC: human-robot co-existence, human-robot cooperation, human-robot collaboration?

When humans and robots are working together, it is often labelled HRC. However, not all deployments of robots in practice, can be characterised as HRC. Within this field, it seems that the C for collaboration is used without distinguishing whether the robots are actually coexisting, cooperating or collaborating with humans. Rather, HRC is used as an umbrella term covering the varying degrees of the working relationship between humans and robots, ranging from human-robot co-existence, human-robot cooperation and human-robot collaboration, in a given work setting. It seems that whenever a human and a robot are located in the same environment – in a workplace – it is labelled HRC, human-robot collaboration. However, collaboration may occur in certain cases, in others. When it comes to mobile service robots in hospitals, untangling collaboration can be quite intricate, as the distinction between simply designing and programming a mobile robot to perform a particular task and genuine collaboration, is determined by the extent of interaction, cooperation, and the achievement of shared goals between humans

and robots. Designing and programming a robot involves creating its hardware and software to perform specific tasks or functions, focusing on the technical aspects of robot development, ensuring that it can execute predefined actions based on programmed instructions [77]. Collaboration, on the other hand, goes beyond the mere functionality of the robot and involves the active participation and coordinated efforts of both humans and robots to achieve a common goal. Collaboration implies a mutual understanding, communication, and adaptability between the human and robot partners and requires the ability to work together, exchange information, and adjust behaviours based on the situation . But do robots hold understanding? Robots, as machines designed to perform specific tasks, do not possess understanding in the same way humans do. Understanding typically involves complex cognitive processes, including perception, reasoning, learning, and the ability to make sense of information in a meaningful way. While robots can be programmed to process and analyse data, they do not possess subjective experiences or consciousness, which are often considered fundamental to human understanding. Instead, robotic responses are based on pre-programmed algorithms, machine learning models, or rule-based systems and they can be programmed to interpret and respond to human cues, gestures, or commands, allowing for a form of communication and interaction. Therefore, the robot understanding must be considered as *the ability to process and interpret information, allowing it to act accordingly in the environment is it situated.* However, the challenge lies in defining what constitutes "appropriate" behaviour for a robot, as it ultimately depends on the intentions and expectations of the humans who design and program it. The humans who typically program robots, do so based on their own understanding of the task or situation at hand, which may not fully capture the complexity and nuances of real-world contexts, in which the robots are to function. Consequently, the programmer/developer do not hold a complete comprehension of the potential scenarios or the specific context in which the robot will operate, which can cause limitations in the robot's ability to *understand* and adapt its behaviour to unexpected or novel situations that fall outside the scope of its programming.
There are no clear, fixed definitions of basic concepts within the field of HRC.
There are different modes of engagement when humans and robots work together, though. These are respectively human-robot co-existence, human-robot cooperation and human-robot collaboration, which holds distinctive characteristics, in spite of the missing clear definitions. The following section sheds light on the nuances and distinctive characteristics of these modes, providing a deeper understanding of their implications for human-robot relationships.

1.2.11.1 Human-Robot Collaboration

Human-robot collaboration refers to a synergistic partnership where humans and robots work together towards a shared goal. Collaboration involves active participation and contribution from both parties, with complementary skills and expertise. In this context, humans and robots engage in a coordinated manner, leveraging their respective strengths to enhance productivity, efficiency, and performance. Collaboration often entails tasks that require shared decision-making, task allocation, and synchronized actions and efficient HRC encompasses the collaboration to take place in a shared environment, where human and robot must participate in joint activities; share work tasks; and have joint intentions, to fulfil tasks [78][79].

1.2.11.2 Human-Robot Cooperation

Human-robot cooperation, although closely related to collaboration, has a distinct focus. Cooperation emphasises the willingness and ability of humans and robots to work alongside each other harmoniously. Unlike collaboration, cooperation does not necessarily require an equal distribution of tasks or decision-making. Instead, it centres on complementary actions and mutual support, with humans and robots working towards a common objective while maintaining their individual roles and responsibilities. Human-robot cooperation often occurs in scenarios where humans provide guidance, oversight, or high-level decision-making, while robots carry out specific tasks autonomously [80].

1.2.11.3 Human-Robot Co-existence

Human-robot co-existence refers to a state where humans and robots occupy the same environment and interact to some extent without active collaboration or cooperation. In co-existence, humans and robots cohabit shared spaces, fulfilling their respective functions independently. The level of interaction can vary, ranging from minimal contact to occasional communication or acknowledgement. Co-existence often occurs in environments where humans and robots operate in parallel but have limited direct engagement [81].

Understanding the differences between human-robot coexistence, cooperation and collaboration, is crucial for the advancement and successful integration of robotics into various settings. Each mode of engagement represents a distinct relationship between humans and robots, with unique requirements and implications. While collaboration and cooperation emphasise shared goals and actions, co-existence focuses on parallel existence, and interaction centres on direct engagement and communication [82].

1.3 RESEARCH QUESTIONS

As shown above, robots have entered application settings they have not historically been used in, to aid and assist humans in various work tasks, with the aim of improving efficiency and relieve humans. The gradually widening deployment of robots increases human-robot collaboration in real-world settings. However, this development causes complex challenges for both robots, humans and the practices and ecosystems surrounding them.
Hence, this PhD project seeks to scrutinize human-robot collaboration in a real-world setting, in hospitals, to deepen the understanding of the complexity of humans and technology joining forces, contributing to the future shaping of collaborations between staff and robots in real-world settings. This is crucial, when ensuring appropriate development, implementation, and use of robots, as there is a need for understanding what the parties do, when they do what they do, to delegate work, coordinate and organise tasks and thereby ensure both humans and robots the best possible conditions for collaboration.

Thus, present PhD project have explored the field through following research questions:

1. *How does the collaboration between service staff and mobile robots unfold in three different hospital sites in Denmark?*

2. *How can empirical findings from three different hospital sites contribute to conceptual insights about HRC in hospitals?*

3. *How can evidence from the scientific literature be used to create a tentative, conceptual framework for HRC in hospitals?*

The three research questions are addressed through four publications. Question 1 and 2 are examined in the three publications communicating empirical findings from conducted field studies (Paper I, Paper II and Paper III). Key elements in a conceptual framework for HRC at work in hospitals are identified in the fourth publication, a scoping review scrutinizing the nature of research within the field and examining recent research of HRC in hospitals. The publication further comprises a conceptual framework for understanding HRC at work in hospitals. By the time of handing in the theses, Paper I and Paper II are published, while Paper III and Paper IV are submitted and in progress.

2 METHODOLOGY: SCIENTIFIC APPROACH AND RESEARCH METHODS

This chapter provides an overview of the approach and methods employed in this PhD study, outlining the approach taken to investigate human-robot collaboration in the context of hospitals. This chapter serves as a guide for understanding the scientific foundations and research techniques used to gather and analyse data.

2.1 SCIENTIFIC APPROACH

This chapter delves into the underlying framework guiding this PhD study and emphasises the importance of adopting a rigorous and systematic approach to generate reliable and valid research findings. The section begins by discussing pragmatism as the overarching scientific approach employed in this study, an approach emphasizing the practical consequences and utility of knowledge, focusing on finding solutions to real-world problems. The approach recognizes the value of combining theoretical perspectives with empirical evidence to develop a comprehensive understanding of human-robot collaboration in hospitals. This enables me as a researcher to answer the research questions in a comprehensive, nuanced way, while adding to my understanding of the practical challenges and opportunities of using mobile robots in a hospital setting, allowing me to develop actionable recommendations for improving the collaboration, onsite. These are to be found in Implications. Next, Phenomenology is introduced as a key philosophical perspective that informs the research by exploring the lived experiences and subjective perspectives of individuals involved in human-robot interactions. By delving into the rich nuances of these experiences, the study aims to uncover the meanings, perceptions, and intentions that shape the collaboration between humans and robots. This is followed by a section about the philosophy of technology as another crucial aspect of the scientific approach, used for examining the social, and cultural dimensions of technology in the context of human-robot collaboration in hospitals. Hence, the study seeks to provide a holistic understanding of its implications. In addition, Postphenomenology is introduced as a theoretical lens that complements the phenomenological perspective, focusing on the ways in which technology mediates human experiences and shapes human perception of the world. By employing this framework, the study aims to uncover the intricate dynamics between humans, robots, and the socio-cultural contexts in which they interact.

The combination of pragmatism, phenomenology, philosophy of technology, and postphenomenology provides a comprehensive and multi-dimensional approach to investigating human-robot collaboration in hospitals.

The scientific approaches provide valuable tools for understanding and interpreting human experiences and interactions with technology in a meaningful and comprehensive way, including staffs' perceptions, thoughts and feelings about working with robots in hospitals. These perspectives inform the research design, data collection methods, and analysis techniques employed throughout the study. By adopting this scientific approach, the study aims to generate valuable insights that contribute to the development of effective and meaningful human-robot interactions and collaboration.

2.1.1 Pragmatism

Pragmatism is a philosophical perspective emphasizing the practical value and consequences of beliefs, ideas, and actions. A pragmatic approach is relevant in present study, as it focuses on addressing real-world issues and solving practical problems.
Pragmatism, with the founding fathers John Dewey and James Peirce, emphasises the significance of action in understanding the interplay between reality, science, and knowledge. As a pragmatic thinker, a researcher takes on the role of a problem-solver, addressing challenges to promote the survival of humanity. The action-oriented engagement of pragmatism implies that inquiries both shape and are influenced by the subject field [83].

Pragmatists believe that problems and their solutions are intricately connected to reality, emphasizing that knowledge and learning are constructed and accumulated through practical experience. Pragmatism typically employs an abductive approach, aiming to develop scientifically sound explanations, which involves the scientist making educated guesses to explain a phenomenon, generating provisional explanations and hypotheses that are subsequently tested. As a result, this approach highlights that the formulation of a problem is followed by the development of a tentative explanation. The objective is not solely to uncover the truth, but rather to solve real-world problems through rational, systematic, and scientific inquiries, ultimately contributing to societal and human progress. Consequently, inquiries and experiments must be connected to reality, to the wild, with the scientific findings' consequences for real-world issues holding significance. Hence, the pragmatic approach prioritizes the practical relevance and applicability of research findings and is characterised by its emphasis on understanding the context and implications of research in real-world settings. It is often used healthcare to improve the effectiveness and efficiency of existing practices and systems.

As pragmatic research is a combination of both quantitative and qualitative methods, it is often used to test the effectiveness of an intervention or to evaluate the impact of a change in policy or practice. The goal of pragmatic research is to provide actionable recommendations that can be implemented in real-world settings, and to make a clear connection between research and practice. According to Dewey, the purpose of thought and inquiry is to solve problems and improve our ability to cope with the challenges of everyday life. His view was rooted in the belief that knowledge and truth are not static, fixed entities, but rather results of dynamic, ongoing processes of inquiry and experimentations. He believed that knowledge is not derived from transcendent, unchanging reality, but rather from our interactions with the world and our ongoing efforts to make sense of our experiences. For Dewey, the goal of inquiry is not to arrive at a fixed, final truth, but rather to continuously revise and improve our understanding of the world through testing and experimentation. He believed that the best way to determine the value of an idea or belief is to put it into practice and see what happens. If the idea leads to positive outcomes, then it has practical value, and if it leads to negative outcomes, then it needs to be revised or discarded. In this way, Dewey's pragmatism emphasises the importance of practical, experience-based knowledge and the role of experimentation and empirical testing in advancing our understanding of the world. It also stresses the importance of considering the ethical and social implications of our beliefs, ideas, and actions [84].

The pragmatic research approach was utilised in present PhD project by conducting research in the wild, utilising methods such as participant observation, shadowing and short, onsite in-situ-interviews, allowing me to gather detailed, real-world data about the phenomena of collaboration between human service staff and mobile robots in hospitals, as it happened. This is valuable for understanding the practical challenges and opportunities arising when these technologies are used in the wild. The goal of this research was to understand the dynamics between the parties and the environment in which they interact and identify ways to improve the value of the work they do. The data gathered was analysed to identify common themes and patterns in the staff's experiences of working with robots. The data collected was analysed to identify common themes and patterns, which provided a comprehensive understanding of the practical challenges and opportunities of using mobile robots in a hospital setting. Overall, this pragmatic research approach allowed me to address a real-world problem in a way that might be useful for practitioners and can have an impact on HRC in hospitals [84].

In summary, the pragmatic research approach employed in this study facilitated a thorough understanding of the practical challenges and opportunities of implementing mobile robots in a hospital setting. The mixed-methods approach used provided a comprehensive understanding of the phenomenon under investigation and allowed me to derive future recommendations/implications for the collaboration between hospital staff and mobile robots, aimed at improving the collaboration.

2.1.2 Phenomenology

The phenomenological research approach is used in this study with the aim of understanding the subjective experiences of hospital staff working with mobile robots – and robots working with hospital staff.

The phenomenological research approach intent to understand and describe the subjective experiences of individuals and is often used in fields such as psychology, sociology, and philosophy, to study the meaning and essence of human experiences. The research typically involves conducting in-depth interviews or focus groups with participants and analysing the data to identify common themes and patterns in their experiences. The goal of phenomenological research is to provide a detailed and rich understanding of the phenomenon being studied [85]. This approach aligns with present PhD project, as hospital staff's experiences collaborating with mobile robots were scrutinized, providing a detailed and rich understanding of their perceptions and experiences.

Edmund Husserl (1859-1938) is one of the founding figures of phenomenology. His approach focuses on the "phenomena", or the things, as they appear to consciousness, and argues that in order to understand the nature of consciousness, we must first bracket or set aside any preconceptions or assumptions about the world - and focus on the raw data of experience. Husserl also developed the concept of "intentionality" referring to the way in which consciousness is directed towards objects and experiences [86][74]. In the context of this PhD project, the concept can be linked to the way in which the staff's consciousness is directed towards the collaboration with mobile robots in the hospital setting, and how they perceive and experience the collaboration.

Phenomenology focuses on the body, senses and practical application, where thinkers such as Husserl, Heidegger, Maurice Merleau-Ponty, Jean-Paul Sartre, Gaston Bachelard and Simone de Beauvoir form the classical school. For example, Merleau-Ponty emphasised the importance of understanding the subjective experiences of individuals, which aligns with the phenomenological research approach used in this study. He also developed the concept of "lived body" (Le corps propre), which refers to the way in which we experience the world through our bodies [86]. This is highly related to conducting fieldwork, where, in present case, I, the researcher, must walk around and around, over and over, to qualify my understanding, analysis, and interpretation of the field [85]. As an ethnographic inspired researcher, I must be able to find my way in the landscape and orient myself, both in terms of having a sense for the details observed and for listening to what I am being told by participants [86]. In present PhD project, I did quite a lot of walking, when researching and gathering data. I followed the robots around for several kilometres in the hospital hallways, my research landscape, which was very sensory. I could see, feel, smell, and hear, which required me to move slowly, allowing myself time to stop and observe, feel, smell and listen – for varying periods of time. At times, my pace was slow enough and focused to an extent, allowing the small cracks and spaces that are not seen in haste, come to light. For example, when I sat down in a hospital laboratory observing a robot standing with flashing lights and a digital countdown, waiting to be interacted with. I saw how they were not noticed – and reflected upon the reasons hereof, before interviewing hospital staff about the phenomena. In the hospitals, there was the characteristic “hospital smell”. According to Dennis Waskul and Phillip Vannini one uses senses of smell to both sense and create meaning, and as an active action [87]. From a phenomenological perspective, smells are primarily experienced in an existential presence and in this case, it added to my experience of *being in the hospital*. Additionally, Merleau-Ponty emphasised the importance of understanding the "lived world" (le monde vécu) which refers to the world as it is experienced by individuals [86]. This relates to present PhD project, as the staffs’ experiences of working with mobile robots in the hospital settings are unique and subjective - and it is important to understand how they perceive and experience the collaboration with robots, in their everyday work environment.

Overall, the phenomenological approach used in this study allowed for a deeper understanding of the field, the robots, the dynamics and the staff's subjective experiences of working with mobile robots in the hospital setting, which provided a more complete picture of the collaboration between human hospital staff and mobile robots in hospitals.

2.1.3 Philosophy of Technology

Don Ihde [88] posits that the philosophy of technology has its origins in pragmatism, positivism, and phenomenology, although Heidegger is often credited as the founder. This branch of philosophy is oriented towards problem-solving and focuses on practical, real-world issues. It also emphasises the investigation of technologies in practice and the knowledge that arises from practical actions. Ihde coined the term "technoscience" to describe the idea that science is embedded in technology, and he describes technology as being connected to humans through various relationships. To address the complex nature of technology, Ihde employs a descriptive definition, which asserts that technology is made up of a concrete component and must be used in some kind of human practice [88].

Ihde provided an explanation of the distinction between technological determinism and social determinism. The former asserts that technology is the driving force that shapes and constructs society, whereas the latter perceives technology as a tool used by the powerful elite to control and oppress. One critical difference between the two approaches relates to the neutrality of technology; social determinists view technology as a manipulative instrument controlled by the elite, whereas technological determinists see technology as non-neutral and influencing the course of human lives. When discussing the philosophy of technology, Ihde highlighted the works of Langdon Winner, Albert Borgmann, and himself [88]. Winner explained how the use of technology creates new forms of human activity and new worlds. He argued that for technologies to function correctly, humans must adapt to them. Furthermore, he viewed artefacts and technologies as political instruments. Winner's main concern was the limits of technology and when technological expansion would reach its end. In contrast, Albert Borgmann believed that technology is like a form of life, belonging to complex and non-neutral human practices. He noted a liberal approach to technology, where its progressive features and benefits to humanity have been highlighted. The optimistic view of technology praises human control over nature, but it cannot solve all human problems as promised. Instead, the liberal approach promotes the importance of material goods and values aligned with quantitative thinking. Borgmann argued that technology is a device paradigm in which various devices are applied as means to an end. In summary, Ihde notes that Winner and Borgmann agreed that technologies are not neutral, generate patterns of human practice or worlds, and modern technologies have taken over larger territories of human practice. Lastly, Ihde emphasised his work on technology, which deals with an interrelation ontology of human-technology relationships [88].

Ihde identified four different types of relations between humans and technology. The first is embodiment, where humans and technology experience the world together as a unified entity. The second is hermeneutic, where technology helps humans interpret and understand the world. The third is alterity, which concerns interactions between humans and robots. The fourth is background, where technology is a part of the context or environment in which humans operate. In all of these relationships, technology plays a non-neutral role and shapes human experiences of the world. Ihde believes that technologies are like worlds or forms of life, and that their impact on human experience is shaped by the particular cultural, historical, and practical contexts in which they are used. In addressing modern technological issues, it is important to be aware of these factors, as technology is non-neutral and has the power to transform both humans and the world. The magnitude and amplification of changes brought about by modern technology only make this awareness even more crucial. Additionally, Ihde notes that technologies are not always used for their intended purpose, which further complicates our understanding of human-technology relations [88]. Ihde's types of relations are built upon in the works of Verbeek, as elaborated in the Theory section.

2.1.4 Postphenomenology

Don Ihde's definition of postphenomenology involves a combination of pragmatism and phenomenology, integrated with technoscience, which views science as being intertwined with technology and influenced by it. One benefit of studying the philosophy of technology is that it allows for an examination of how technology is connected to and affects social and cultural aspects by conducting empirical studies that are contextualized and specific. Postphenomenology, as a theoretical framework, facilitates the exploration of technology in action and how it operates in real-world scenarios. Postphenomenology investigates the interactions between humans and technology and operates on the premise that technology is not a neutral tool simply utilised by humans. Rather, humans and technology mutually influence and shape each other, ultimately impacting the structure of human existence and the world at large. This perspective on the relationship between humans and technology is rooted in an interrelated ontology that is embedded in human practice. To understand the nature of these interactions and how technology and humans impact each other in practical settings, it is necessary to conduct contextual studies and analyses utilising theories and concepts that are rooted in the postphenomenological tradition. It's worth noting that technology is multistable, meaning that its form and usage can vary depending on the context, with cultural factors having a significant influence [89]. Don Ihde's discussion of how technologies influence our lived experiences highlights the significance of how various worlds can be created through their use. This is a key area of interest in present PhD project, which employs ethnographic methods to attain a genuine comprehension of mobile robots in hospitals and their interactions with service staff in practice [5]. The objective is to develop practical and valuable interdisciplinary approaches that can be applied at both a practical and societal level. This makes it a useful method in situations where differences arise concerning a specific technology between professionals, users, cultures, and stakeholders, or when the consequences of using a particular technology are unclear [5]. As such, the approach seeks to provide workable solutions that can be implemented to address these discrepancies.

2.2 RESEARCH METHODS

In the following section, the research design and the data collection methods applied in present PhD study will be elaborated upon.

2.2.1 Research design

The research design employed in this study was a multiple case study that aimed to understand the phenomenon of human-robot interaction in hospitals. Fieldwork was conducted at three hospital sites [90]. The use of multiple cases provided a deep, comprehensive understanding of HRC in hospitals and allowed for the examination of similarities and differences between the cases.

The qualitative inquiry was characterised by being a research in the wild study, aiming to understand HRC in naturalistic settings within the context of socio-technical practices. The study population consisted of 12 mobile robots and 61 hospital staff members in the three selected hospitals. The sample for the study was selected through a mix of snowball sampling and convenience sampling, while data collection took place through participant observation, interviews, and shadowing. The collected data were analyzed thematically..

2.2.2 Research in the wild

Research in the wild (RITW) studies focus on understanding human behaviour in naturalistic settings and within the context of socio-technical practices, as being the case in present PhD project, investigating HRC in hospitals. In this type of study, the attempt is to understand how people use technology in real-world settings. By studying how hospital service staff and mobile robots interacted and collaborated in their daily working lives, RITW allowed me to gather data that could be used to improve the collaboration between humans and robots in real-world settings and contribute to future concepts for human-robot collaboration in the wild [91]. There are many ways to scrutinize human approach, use, engagement, ignorance etc. of technology, which is the primary focus for RITW; typically, a RITW project involves some kind of a novel technology deployment in an unconstrained environment and an evaluation of how people respond to the deployed technology [92]. Thus, researching robots in the wild offered a valuable opportunity to investigate HRC within natural context, capturing the intricacies and complexities of human-robot interactions and collaboration in authentic environments, in contrast to controlled laboratory studies and studies of robots collaborating with humans in industrial settings, as robotics research has traditionally been focusing on. By instead emphasising real-world scenarios, where HRC systems are deployed and utilised in everyday contexts, it is possible to acknowledges the importance of various contextual factors, such as social norms, cultural influences, and environmental dynamics, which can significantly impact the effectiveness and acceptance of HRC systems. In addition, this approach allowed for the observation and analysis of authentic behaviours, attitudes, and challenges encountered by individuals and groups engaging with HRC systems. Further, it facilitates a better understanding of the broader societal implications and ethical considerations associated with the integration of robots into human-centric domains.

In the present PhD project, the deployed methods included observations, field notes (including photos and video), interviews, and shadowing. The approach could be characterised as unstructured, and while it may have seemed unwieldy, it opened up new possibilities for conducting far-reaching, impactful, and innovative research. It also became an increasingly accepted method for conducting research in human-robot interaction, complementing traditional lab-based research method [91][92].
One of the benefits of RITW is its increased ecological validity as it allows for in situ study of how humans interact with robots in their everyday lives, in contrast to controlled laboratory based experiments, through which most research on HRC has yet been conducted. Laboratory studies are less likely to reveal everyday life aspects of the interaction and collaboration between humans and robots, as the parties operate in a synthetic setting and as humans may conform to experimenters' expectations and the artificial environment in this type of study. Lab-studies are well-planned and highly structured and there are still likely to be many reasons for continuing research in controlled lab-settings, especially when it involves testing new interfaces and interaction techniques intended to help people develop skills for new application areas, such as learning to perform surgery or fly an airplane. On the other hand, scrutinizing robots in a naturalistic setting, allows researchers to explore everyday use and investigate how a range of factors can influence the collaboration between humans and robots. It is not a matter of one approach being better qualified than the other, but rather a question of when to conduct a lab study and when to conduct a RITW study [93]. The insights gained from this approach can inform the design, development, and implementation of HRC systems, addressing real-world needs and improving user experiences. One of the aims of this approach is to uncover valuable insights into the dynamic interplay between humans and robots, further enhancing the comprehension of HRC in real-world contexts. For the purposes of this study, the RITW approach was chosen because the aim was to understand HRC in hospitals and gain comprehensive insights into how humans and robots collaborated on everyday tasks within a specific naturalistic setting: hospitals. Consequently, RITW was used to gain insights into the teamwork between hospital staff and mobile robots and to explore assumptions, investigate hospital staff's reactions, and integrate robots in relation to their work, both in terms of culture and tasks.

2.2.3 Ethnographic inspired data collection

The research conducted in this PhD project is qualitative, based on ethnographic inspired methods for collecting data. According to Hammersley and Atkinson, the aim of researching ethnographically, is to produce valid knowledge and challenge status quo. Hence, the ethnographic method is not standardised nor sharply defined, it overlaps with other qualitative approaches and can be used as an umbrella term, covering several qualitative research methods, such as fieldwork, case study research, cultural studies etc. However, the lack of uniformity, rooting in

the complex history of ethnography[1], does not undermine the research approach, as the purpose of ethnographic research is to produce valid knowledge, by conducting first-hand empirical explorations and investigate interpretations of social organisations and culture.
In this study, the knowledge production was generated based on three cases exploring robots and humans, and their work processes and practice, through fieldwork, consisting of observational studies, guided tours, interviewing humans and shadowing/following mobile robots around, over a period of time in three hospital sites [94–96].
This is aligned with the ethnographic knowledge production process, as in ethnographic research, knowledge is generated based on few, deeply explored case studies. The knowledge is affected by the researcher, who must reflect upon her own accountability and consider how to manage her influence on participants, instead of trying to minimize the effect on participants by distancing themselves. As a researcher doing ethnographic inspired data collection, one must simply be upfront about one's impact. I tried to limit the impact I had on the informants in this study, for example by asking neutral, open-ended questions when interviewed, adopting a more passive role, allowing the informants to freely express their thoughts, opinions, and experiences without imposing any specific direction or bias. This, as the primary goal of interviewing hospital service staff, was to gain understanding about their subjective experiences and perspectives. Thus, I seeked to preserve the authenticity and richness of the data collected. In addition, I was transparent about my being in the field, presented myself as a PhD student researching how robots and staff worked together.
An ethnographic inspired data collection calls for an epistemological discussion of researcher involvement, research effect, bias, and field bodies, as the vast amount of material generated by such research, necessitates a reflexive engagement by the researcher, both regarding the emergence, significance, and dissemination of data. Despite the temporal and spatial limitations of fieldwork, it inevitably prompts reflections on one's own positionality, preconceptions, and biases. These considerations are commonly encountered by ethnographic researchers as they navigate the challenges of interpreting and understanding their research subjects. The question of whether we are only seeing what we want to see, the determination of what is deemed important or insignificant, and the pursuit of understanding the inconceivable, are all considerations that must be considered. Hence, the importance of researcher intentionality.
My awareness of these challenges played a critical role in the fieldwork. Through self-reflection, ongoing evaluation of questions and methodological commitment, I aimed at pursuing a comprehensive understanding of the complex environment and the phenomena herin. These intentional efforts contributed to the reliability, validity, and credibility of my research, enabling a more nuanced and robust analysis of the collaboration between hospital service staff and robots.

[1] The ethnographic approach holds a complex history, being influenced by anthropology, sociology, and cultural studies, and inclined from different fields and sub-fields. Gradually, the different disciplines have influenced ethnography with theoretical ideas and -isms, reinterpreted and recontextualized the approach, resulting in an unstandardised definition and diversified the social settings in which the approach is used.

It is widely acknowledged that any researcher will always influence the field and be influenced by it in turn - and researchers are inherently embedded in cultural and historical contexts. Consequently, the knowledge produced must be viewed within a political, cultural, and historical perspective. This understanding has led ethnographers to focus on self-reflection, one's own preconceptions, and how to represent the perspectives of others. Central to this is Clifford Geertz's discussions on the role and insight of ethnography in the field. By examining the various types of meanings that can be attributed, analysis is created based on the deeper understanding that ethnography has gained through fieldwork. Geertz worked with an interpretive approach that takes its starting point from the actors' description and interpretation of their own activities. In addition, James Clifford and Georg E. Marcus problematized the Western anthropologist's authority to represent other people's culture and sought to find forms of representation where the others themselves came to the fore. They emphasised that the democrat's own position in the field will always be a being-in-the-world and that the first-person perspective will mean that ethnography produces partial truths. Being-in-the-world is not only about physical location but also about political power relations and biographical conditions such as gender, age, and different life experiences, which may be decisive for how the studied world appears and for what type of knowledge and data one has access to [97][98]. Anthropologist Charlotte Aull-Davies has proposed reflective ethnography as a way to work with the researcher's own position, roles, and autobiographies [99]. Doing fieldwork is obligated to ethics, which must constantly be reflected upon, depending on the materials and phenomena being studied. The ethics in my field studies are elaborated in section 2.2.14.

2.2.4 Fieldwork

In present PhD project, I conducted fieldwork in three different settings, two hospitals in three different locations. Fieldwork is a scientific discipline which involves establishing a place in a given, natural setting on a relatively long-term basis, immersing oneself in a culture, while learning as much as possible about it. If the conditions were perfect, I could have immersed myself into the field sites for a longer period than I did. Reality is however, that ethnographers often must make do with what they can access and utilise the opportunities that are available to them [100]. For me, the fieldwork was scheduled to take place during 2020, but suddenly the covid-19 pandemic hit the world and consequently, it was difficult to access the field, when the field was hospitals.
However, I managed to get access and collected data at the two SHS hospitals in 2020.
In the latter part of my PhD period I decided to undertake fieldwork once again, to collect more – and newer – data. I managed to get access to OUH, a large Danish University Hospital, having mobile service robots installed. I went there in late 2022. For more details on getting access to the field, please see the paragraph “Access to the field and participants”, section 2.2.8 in this chapter.

The aim of the fieldwork conducted in this study, was to explore, scrutinize and experience the shared working life, work environment, relationship and dynamics between hospital service staff and mobile robots - and the dynamics between them, the processes occurring, and the environmental factors influence on these, in the hospital settings. This comprised getting close to both hospital staff and robots; close enough to make them feel calm around me as a researcher, so I could learn about their everyday lives [101].

2.2.5 Investigating the unnoticed

By investigating ethnographically, I was able to obtain nuanced and detailed descriptions of the overlooked aspects of the everyday collaboration between hospital service staff and mobile robots, shed light on the unnoticed elements of their being and scrutinize how the parties did what they did; how they practiced their everyday doings and how activities, routines, rules and daily cycles were handled and experienced. In my reach to seeking to understand HRC in hospitals, I needed to explore the dynamics, the details and the unnoticed and gain insights on such and be able to identify elements that may thrived in the shadows and had no desire to go from unnoticed to noticed.
The "unnoticed" can be understood as something that is overlooked, or something that one cannot or will not see, or something that has been forgotten or is not worth remembering. Exploring what is commonly regarded as insignificant - such as background, the banal, the overlooked, the routines, the immediately obvious - can provide insights into how individuals create meaning and understand their lives, as well as how society functions [102] [103]. At some points, I became irritated when all these everyday routines and everyday banalities did not seem interesting in themselves, and I feared that my research was going nowhere. At times, I started to fear that the project would just drop to long ethnographic descriptions of random events occurring at the hospitals, without greater connections to society or other contexts. However, by studying the small stories, such as going deep into hospital staffs' perceptions of robots (for example by being guided through hospital hallways while being told tales of the field – such as narratives on how service staff tended to shot down robots and hinder them in driving the hallways, hindering them in performing their tasks); unusual perspectives (such as taking on the robots' point of view); and everyday discrepancies, one can gain a more comprehensive understanding of the larger narrative and consequently, the examination of small details can be just as valuable as studying bigger, more dramatic events [86].

2.2.6 Fieldnotes

As a researcher influenced by ethnographic methods, collecting a diverse range of information through participant observation, including descriptive notes, photos, audio and video recordings, formed one of the bases in my study. A prevalent technique for documenting the observations, both in present study and in ethnographic research in general, is to take field notes, which involves making many small notes - instead of one long-running narrative - and organising them into separate files - rather than constantly updating a single one. The process of description involves not only recording what is seen, but also making sense of what is observed and deciding what is relevant to include in the notes. This requires the observer to bring their own perspective, biases, and assumptions to the process, shaping the final representation of what has been observed. I brought a guide for observation with me into the field sites, however it was very open and unstructured and consisted of unstructured notes on HRC, based on literature within the field. By doing so, I partly knew what I was looking for but was not restrained or delimitated and thereby able to keep an open approach to the field [101].

Participant observation and field notes are important tools in the ethnography process, as they are written accounts produced in - or near - the field, typically contemporaneously with the events, experiences, and interactions they describe. In the case being, field notes were conducted onsite in-situ, in the three hospitals.

Taking notes is an essential part of ethnographic research, as it allows the researcher to capture the details and experiences of their observations and interactions with the field and with their informants. Field notes are accumulated over time, on a day-by-day basis, without a consistent underlying principle, and with the understanding that not all observations may be relevant for a larger or completed project. As a result, a corpus of field notes often includes fragments of incidents, drawings, incomplete narratives, accounts of changing circumstances and infrequent events, as well as details of a diverse array of unrelated matters. Some of my corpuses of field-notes were written into whole bodies of text post-fieldwork, which gave me a chance to become even more familiar with the data, information and insights brought home, making my understanding of the field even more comprehensive.

According to Bernard, there are four types of field notes [101]:

1. Field jottings (short notes made on the spot during observations and interviews, useful for capturing details that may be forgotten later: a few keywords to support the mind and trick it to remember).
2. Diary notes (personal records that may not necessarily be included in publications, but rather serve as a way to process and deal with emotions that may arise during field-work)
3. Logs (records of how time and money are spent during fieldwork, important for conducting systematic research) and
4. Field notes (the documentation of observations as soon as possible, in order to capture as many details as possible).

Further, there are three types of field notes that are commonly used in ethnographic research: methodological notes, descriptive notes, and analytic notes. Methodological notes document the techniques used for data collection and can be useful for sharing with others to improve the research process; descriptive notes are the mainstay of fieldwork and are typically collected through observation and interviews. It is important to capture the details of behaviour and the environment in these notes. Analytic notes are a small subset of the field notes, where researchers document their ideas about how the culture they are studying is organised. These notes are the product of understanding gained through the organisation and analysis of descriptive and methodological notes over time. It is important to continue writing analytic notes, even after leaving the field.

Figure 4 A boy following one of the robots at OUH.

The field notes in this study primarily consisted of field jottings, photos and field notes, for example: *Esben's den is an inferno of clutter, robots, cables, boxes, notes and drawings, tools, magnets and buttons, screws and small things, small robot figures, coffee in the pot, empty bottles, pictures of robot gear, prototypes, wires and gadgets. He gives me a lab coat that smells characteristic of a hospital, "This one is completely clean. Just put it on, then you can walk around freely without anyone asking questions. Then you can look like a doctor," he says.*

Another example is this:

In the corridor at Blood Samples I sit and watch, a female BA comes, fills samples in Hubot and loudly exclaims: "ANYONE HAVE SOMETHING FOR HUBOT?!!!", "NO!" comes back. She sends Hubot on and it drives away. Hubot drives out on the corridor, stops because a patient quickly goes in front of it. People look at it, smile at it and talk about Hubot. They see it as a bit of a fun gimmick, I can hear. "Is that you controlling it?", I am often asked, when I walk around behind the Hubots. "OH!", exclaims a woman, on the corridor, as Hubot comes towards her. A little boy follows after Hubot, he thinks it's cool, he says to his parents.
"Just look, mom, it just drives all by itself, like this!". Old lady drives a wheelchair into Hubot.

Figure 5 My pocket

And this:

At times, I sit on the corridors and observe how the staff interacts with the Hubots. Most often, a Hubot is standing unnoticed on the corridor and waiting for emptying and refilling. The staff is so used to the robots that they don't notice them. Most people call Hubot "he".

Figure 3 *Esben's desk with screen to monitor the robots on, in the den in the hospital basement at OUH.*

However, there are also few examples of diary notes, such as this one:

I reach a point where I need something sweet to keep me going, so I rush to the hospital kiosk and buy candy. To my great appreciation, it turns out that a bag of M&M's fits perfectly in the pocket of a lab coat. I find comfort and luck herein, as no one can see that I run on chocolate - and then I move further on.

Field notes are selective in nature, as the researcher chooses to write about certain things deemed significant, ignoring others that may not seem important. Additionally, field notes present events and objects in a particular way, and may miss other perspectives or interpretations [104]. I could have decided to not include my need for sugar and the act upon it in the field-notes. But rereading the passage post-fieldwork, immediately takes me back to my state of mind in that time, and the picture of the M&M's bag fitting in the coat pocket takes me back to the feeling of relief and comfort, I felt back when it occurred. Geertz has emphasised, in writing down social discourse, the ethnographer 'turns it from a passing event, which exists only in its own moment of occurrence, coming into an account, which exists in its inscription and can be reconsulted' [105]. A selection of my field notes is to be found in the Appendix, chapter 10.

2.2.7 Participant observation

Participant observation comprised the backbone of the data collection in this PhD project and was utilised to gather data, information and insights on human-robot cooperation in hospital settings. When aiming for gaining insights into behaviours, and when investigating the unnoticed, observational studies are crucial. Participant observational research is a fundamental method used in ethnographic research - as well as in social and behavioural sciences - as it allows researchers to collect various types of data, including narratives, numbers, and graphic materials, by immersing in the world and cultures they are studying [106]. A widely accepted framework for Participant Observer Roles is the one designed by Gold outlining the different ways in which a researcher can participate and observe in a study setting [107]. The typology includes four distinct roles: 1) the complete participant, 2) the participant as observer, 3) the observer as participant, and 4) the complete observer [105,107].

Table 4 Gold's typology of the participant roles in observations [107]

Role	Description	Example
Complete Participant	The researcher becomes fully part of the setting, taking on an insider role and often observing covertly.	Observing and participating in a religious ceremony as a member of the community.
Participant as Observer	The researcher gains access to the setting based on a natural and non-research reason for being there. They are part of the group being studied.	Joining a soccer team and participating in their practices and games to observe team dynamics and social interactions.
Observer as Participant	The researcher has minimal involvement in the social setting being studied, with some connection to the setting but not being a natural and normal part of it.	Attending a community event as an observer to study crowd behaviour and dynamics without actively participating in the event.
Complete Observer	The researcher does not take part in the social setting at all and observes from a distance.	Watching children play from behind a two-way mirror to study their behaviour without directly interacting with them.

In case of present PhD study, I adopted the role of an observer as a participant. This role allowed me to maintain a certain level of distance while still being actively involved in the hospital setting, I was studying. Thus, I was able to carefully balance my participation with my role as an observer, allowing me to gather valuable insights while having a minimal involvement in the social setting. While I had some connection to the setting, I was not a natural and normal part of it; thus, the hospital staff did not know me, instead they knew I was an outsider. However, they knew I was conducting research on the robots, which helped me maintain a careful balance between participating in the activities throughout the day and observing them from a research perspective. This allowed me to interact with the participants naturally, building rapport and trust, while also remaining vigilant in my observations and documenting important details – and thus provided me with the opportunity to gain understanding of the dynamics at play. This may have been difficult to attain solely through traditional observer or participant roles.

2.2.7.1 Stages of participant observation

According to Bernard there are seven stages of participant observation [101]. These are illustrated in the graphic below:

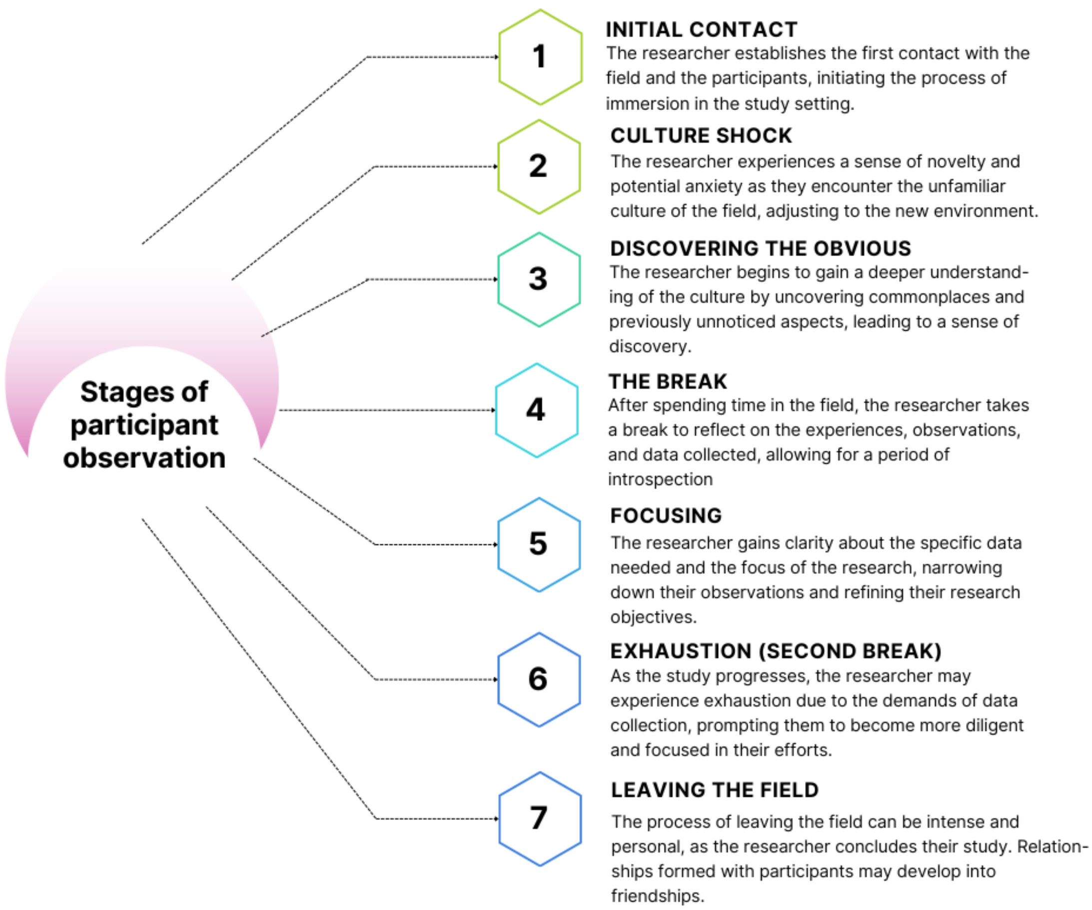


Figure 6 Stages of participant observation according to Bernard [76]

In my case, after the initial contact was established in present PhD project, and as my hands was on the edge of getting dirty in the field, I experienced a mix of the initial novelty, concern and culture shock: I got overwhelmed by the setting and the elements herein, all the sensorial inputs: the smells, the lighting, the sounds, the temperature; the long hallways, the different types of people (patients, visitors, healthcare professionals, service workers, workmen, cleaning staff) each with their own stories, agendas and behaviour. I got amazed at the first glances of the robots, as the first day of the first fieldwork, was my first time ever to be physically close to a robot. The field also hit me in terms of navigating. In all three hospitals, it was difficult for me to get an overview of where the robots were driving, as I had never entered these specific hospitals before and the navigation around the hospitals were challenging for me, as all three of them were large buildings with long hallways and logics that were not easy for me to grasp at first sight, as I am not a great navigator. I doubted that I would be able to find my way around the hospitals and feared that I might miss out on important insights on that account. I was astonished by seeing the robots in action and by seeing the responses they generated, while driving the hospital hallways. It came upon me, that I did not have to be able to navigate the hospitals, as I would simply just follow the robots around. In all three fieldworks conducted, my notes were thickest and richest, and the photos and videos were large-numbered, in the beginning of the stay, as I was blown away and had to jot it all down, as it occurred and happened, to ensure later remembrance. I was stating the obvious – but since the obvious was novel to me, I noted down as much of it, as possible.

Field notes are an expression of the ethnographer's deepening local knowledge, emerging sensitivities, and evolving substantive concerns and theoretical insights [104]. As are my fieldnotes, and rereading them post-fieldwork, it stands out how I gradually became more familiar with the surroundings, the environment, the humans and the robots, and started to understand more about the field and about the collaboration between the two parties. As my understanding rose, I started to discover other, less obvious, elements, such as workarounds where hospital staff did not collaborate with the robots because of different factors. After each day of being in the field, I would take a break to digest it all, which helped me get a clearer understanding of data. At the end of each field work, I dedicated a specific number of hours to look for elements that I felt could be further expounded. As I left the three field sites, I said proper goodbye to the contact persons that had granted me access. All of them stated that I would always be welcome to visit them again and after the data collection, we have mutually reached out and are part of each other's networks.

2.2.8 Access to the field and participants

Gaining access to the field can be challenging as it has several dependencies [95].
For example, the access depends on gatekeepers and in this project, I learned the importance of helpful gatekeepers. Access to the field was tried in early 2020, just as the Covid-19 pandemic had laid its shadows all over the hospital sector in Denmark (and the rest of the world). Consequently, gaining access to do fieldwork in hospitals was difficult. I sporadically tried to kick down doors to hospitals in different places in Denmark, without positive outcome. It was extremely difficult to get access to hospitals, because of Covid-19. However, by reaching out to my network within the Danish healthcare sector, Christian Nøhr connected me with Conny

Heidtmann from Southern University of Denmark. Throughout the PhD project, Conny – and her helping spirit - has been great, especially regarding field access. Conny helped me, through her own network within robotics in healthcare, gain access to the three hospitals I conducted fieldwork in, and I am her extremely grateful. First, Conny connected me with Jan Toft from the Hospital of Southern Jutland, who sat me up with Nana Veronica Beck, who forwarded my request to Rikke Larsen, kitchen manager from SHS. From there, Rikke connected me with Charlotte Høi, the Assistant Manager from the hospital kitchen in Sønderborg and Jan Jørgensen, the Assistant Manager from the kitchen in Aabenraa. I planned with both Charlotte and Jan via e-mails and visited their sites in Spring/Summer 2020. Both Charlotte and Jan were great in welcoming me to their hospitals, showing me their robots, introducing me to their teams and let me conduct my studies, in the middle of the raging pandemic.
In 2022 Conny sat up a meeting between her, me and Thiusius Rajeeth Savarimuthu from the MMMI SDU Robotics, who granted me access to OUH. At a healthcare and innovation fair at the Danish Technological Institute, he pointed me to the Technical Manager from OUH, Esben Hansen, who granted me with an open mind and helpful approach.
From the very first contact, Esben was willing to help me, talk about robots and hospital, tell me about the installation of robots at OUH and a give me rich descriptions of both robots, environment, staff-robot collaboration, difficulties, negatives and positives, and other stuff, which gave me a very comprehensive understanding of the robots at OUH.
At OUH, Esben introduced the staff to me. We walked around the hospital and greeted the staff I would encounter throughout the fieldwork, so they knew who *the lady following the robots* were. A researcher's entry into an organisation can have a decisive impact on the way the researcher is received, the level of trust shown to the researcher, and the areas of organisational life that the researcher is able to access. Esbens introduction allowed me to get close to the hospital staff when they worked and collaborated with the robots. I could feel that most of the staff trusted Esben and had a positive relation to him, which affected their ways of approaching me, as they associated me with Esben. This became clear when they told me about the robots, they thought that I had technical knowhow and for example asked me if I could help Esben fix certain issues. I could feel that I was in a position of trust, because they trusted Esben. They trusted him to support the robots and his efforts herein. However, not all staff members agreed upon Esben's view on the robots. One of the staff members were critical towards him and told me that:

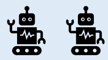
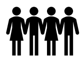
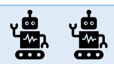
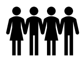
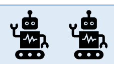
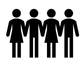
> *"I can't tell Esben this, so you can't tell him I said this to you.. But the Hubots are causing problems. They just stop. THEY STOP! They've also stood in front of each other and said 'please step aside', to each other - that happens often. [...] We can't tell Esben. Because he thinks the robots are so fantastic. You shouldn't say anything bad about it, oh no!"* [unpublished]

Staff associating me with Esben influenced the insights I was getting from the interviews, as they told me both positive and negative sides of collaboration with robots and I did not find it problematic for the data collection to be associated with the technical management, as the staff clearly had a trusting relation with him. If they have not had that, they would probably have been more critical towards me and my being in the field and felt under negative surveillance.

2.2.9 Participants

The participants in this study consisted of both robots and humans. In the table below, the participants are illustrated sorted by hospital.

Table 5 Overview of humans and robots participating in this study

Hospital	Participant Type	Participants
SHS Sønderborg		Prop, Berta
SHS Sønderborg		16 kitchen staff 6 porter staff 2 managers 1 healthcare professional
SHS Aabenraa		1, 2, 3, 4, 5, 6, 7, 8
SHS Aabenraa		10 kitchen staff 2 porter staff 2 technical staff 1 manager
OUH Odense		Hubot1, Hubot2
OUH Odense		1 cleaning staff 18 medical laboratory technologists (MLTs) 1 technical manager (TM)

The participants were sampled through a mix of convenience sampling and snowball sampling, as the recruitment of hospital staff occurred continuously as I walked around the hospitals, establishing contact and relations with staff. The sampling methods were thereby utilised as I followed the robots around and came across human hospital staff who I interviewed in-situ, as it was convenient to do so, when approaching them. Additionally, human informants were progressively recruited by snowball sampling, based on their interaction and collaboration with the robots [108].

2.2.10 Description of the field

The fieldwork was conducted in three different locations, at two different hospitals in Denmark. The sites are described below.

2.2.10.1 SHS Sønderborg – May 2020

The hospital in Sønderborg was a medium-sized Danish hospital with approximately 3,000 employees across its operational region, which covered a population of around 228,000 people. The hospital had two other unites, at the unit level in this study, the core task was mainly to carry out planned same-day surgeries, treating and monitoring chronically ill citizens, and treatment of injured locals and outpatients [109][110].

The hospital had deployed mobile service robots to operate in the basement in 2016. The robots were of the type MiR Hook 100 which is a mobile robot developed for industrial use, with a hook. The hook was used for attaching the carts that the robots transported across the basement, where they were installed. The robot was an autonomous mobile robot, a type widely utilised in industry, where it primarily operated without human interaction. However, this type of robot had gradually gained acceptance in this hospital as a means of optimizing logistics. As a result, the robots interacted with humans in a dynamic environment in the hospital basement. The robots identified service carts that needed to be retrieved from various hospital locations using QR codes and were equipped with sensor input, enabling them to assess the current setting and avoid collisions with both human and inanimate obstacles. Additionally, both robots featured a large, red 'STOP' button that, when activated, halted the robots immediately in the event of an emergency and a joystick for manual operation. The robots communicated with their surroundings through sound and light signals, indicating the intended direction and the status of the current tasks they were executing.

Figure 7 One of the robots, Prop, recharging in the dock in the Robot Garage in SHS Sønderborg

The robots were named Prop and Berta by the kitchen staff, who voted on it during an election at a New Year's party. According to the hospital kitchen management, the names created trust in the robots and made people treat them with kindness. Prop and Berta were installed in 2016 to alleviate the burden of the hospital kitchen staff, who were tasked with the responsibility of conveying heavy carts of cutlery, dishes etc. through the hospital basement.

The robots did only operate in the basement as there was a fear that they would cause frustrations and errors, if they were to function in other parts of the hospital. Further, the robots belonged to the hospital kitchen and were supposed to aid the kitchen staff, who spent time transporting carts around in the basement. The hospital kitchen was on another floor, but the robots were unable to ride the elevators (because the robots' size made them incapable of fitting into the elevators when carts were attached) and could not access the kitchen. Consequently, the kitchen staff transported carts with cutlery, dishes etc. from the kitchen floor, down to the basement. When in the basement, the staff placed the carts in certain spots, such as the Robot Garage or the hallway, for the robots to pick them up. The Robot Garage was an old, emptied storage room where the robots' charging docks and a tablet connected to the robots were placed. Just outside the garage, the elevator that the robots were using, was located. From that spot, the robots could collect a cart and transport it to another destination (e.g. Temporary Destination A as seen in Figure 8), where a member of the kitchen staff would take the cart and transport it to Final Destination B, which was usually located on the higher floors of the hospital.

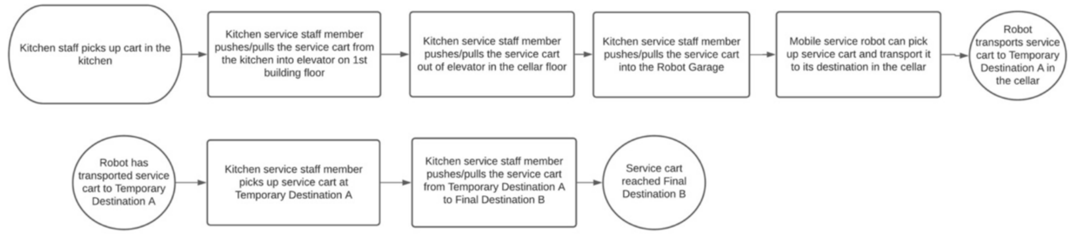


Figure 8 A visualisation of the observed steps for transporting a service cart from one spot to another[1]

The basement hallways were narrow, and the traffic was mixed, consisting of both patients, clinicians, laboratory technicians, kitchen staff, porters, technical staff, and workmen, each with their own behaviour, pace of walking/working and own agendas. Consequently, the environment was characterised by being dynamic, unstructured and unpredictable, which made the completion of transporting and placing service carts difficult for the robots.

The ethnographic inspired field study of the interactions and collaboration between the robots and hospital kitchen staff, was conducted in May 2020. The study comprised participant observation, short onsite in-situ interviews and guided tours. The observational studies were occupied with Prop and Berta and the humans that surrounded them as they carried out their daily routines and duties, both independently and in collaboration with humans in the basement. Short onsite in-situ interviews were conducted, to gain a comprehensive understanding of staffs' notion of the collaboration with the robots. The hospital staff who participated in interviews, 16 of whom were kitchen staff, were recruited through snowball sampling with the aim of investigating their daily routines and perceptions surrounding their experiences of working with mobile service robots. Lastly, the kitchen staff provided me guided tours, during which they detailed their tasks and routines and illustrated how the robots were, or were not, integrated into these.
The purpose of utilising this combination of data collection methods was to examine the setting; gain insight into the presence of robots in the hospital; examine the collaboration between this type of technology and humans; and to explore if human expectations for cooperation with robots were clear, considering the robots' effect on the work environment.

Figure 9 Robot with cart attached driving the narrow hospital hallways at SHS Sønderborg

Figure 10 Robot driving the narrow hospital hallways

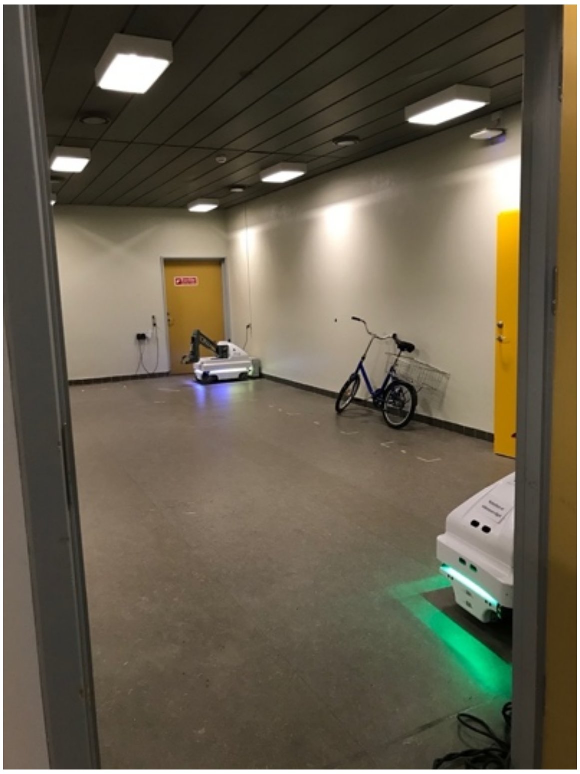


Figure 11 The robots Prop and Berta in the Robot Garage in SHS Sønderborg

Figure 12 Patients and robot with cart attached

Figure 13 Robot placing carts in Robot placing carts in the hallways at SHS Sønderborg

2.2.10.2 SHS Aabenraa – July 2020

The other field site of this study was the hospital in Aabenraa, which is a unit of the same organisation as the hospital in Sønderborg and located near it. The hospital in Aabenraa primarily treated emergencies, children and pregnant and labouring patients.
The hospital had installed 8 mobile robots: five elder mobile robots (named 1, 2, 3, 4 and 5), deployed in 2012, and three newer mobile robots (named 6, 7 and 8) deployed in late 2019. 6, 7 and 8 were able to load and unload carts autonomously by driving beneath the carts and elevate themselves, while 1, 2, 3, 4 and 5 had to be loaded and unloaded by hospital staff. The robots were the type TUG from Aethon.
The robots were able to ride elevators and drove from their base in the basement, up to the hospital kitchen and onto various hospital wards to place/pick up carts with dishes and cutlery. The robots primarily drove to the back rooms of the wards.

It was primarily one member of the technical staff group who had the maintain and look out for the robots and troubleshoot in case of errors. If he couldn't troubleshoot the robots, he would call Aethon who immediately could support him. However, the technician had other tasks and responsibilities besides the robots, but he spent a great amount of his working hours to attend to the robots. The hospital environment shared by robots and humans were relatively suited for this with some open spaces, in which the robots were able to navigate around obstacles and humans.

Figure 14 Robot with cart loaded driving the hospital hallways at SHS Aabenraa

2.2.10.3 OUH – November 2022

Odense University Hospital is one of the four university hospitals in Denmark, collaborating with the University of Southern Denmark. OUH has approximately 11,000 employees across its operational region [111]. The hospital specialized in treating a range of complicated illnesses, including heart and vascular diseases, cancer, and replantation of fingers, hands, and more. As a result, the hospital also provided treatment to patients from different parts of Denmark and, in some cases, even from abroad.

The hospital had installed a range of robots, as they had a close collaboration with a large robot company, who gave them access to robots specialised in transporting various items around the hospital, which consequently functioned as a testbed. This research focused on two autonomous mobile robots (AMRs) for carrying blood samples around the hospital. The two mobile service robots operated on the ground floor and 1st floor and were named respectively Hubot and Hubot2. At the time of data collection, in late November 2022, Hubot had been deployed in the hospital for four years while Hubot2 had been working at the hospital for 3 weeks. The name Hubot2 was a direct consequence of this robot being deployed after Hubot. In daily routine, the hospital staff had nicknamed Hubot *Big Hubot* and Hubot2 *Little Hubot* and *Mini Hubot*.
The robots were of the type MiR 200, an autonomous mobile robot, developed for industrial use. They could carry between 100 and 1350 kg, depending on the model, and were equipped with scanners, cameras, and speakers that functioned as the robot's eyes and ears, with the aim of allowing them to operate and navigate around people and objects on the way.

Figure 15 The two robots at OUH

Besides the MiR200 mobile robot, the Hubots were built by a Technical Manager (TM) at the hospital, who created the Hubots from bits, pieces and stuff he had in stock in his office/robot garage. The Hubots both have a cabinet on top, in which blood samples are stored when the robots drive. In Hubot there were three baskets inside the cabinet, while Hubot2 had one single box for storing blood sample racks inside its cabinet. Both Hubots had a lock, an emergency STOP button and a smartphone attached to it, from which the hospital staff could lock/unlock the robots, stop them, and send them on missions.

The robots were deployed to take on courier processes and transport blood samples around the hospital. Hubot would pick up blood samples in Clinical Genetic Ambulatory Unit at the first floor and drove them down to the laboratory in the hospital ground floor. Hubot2 was picking up blood samples in the children's' hospital at the first floor and drove them down to the laboratory in the hospital ground floor. By doing so, the Hubots were relieving staff from walking approximately 8 kilometres, 2.5 hours, with blood samples, every day. The robots were sent off on missions by both the Technical Manager and by the laboratory staff, via computers (on which staff could also follow the robots, see where they were, see if something was in the way etc.) or by the use of the smartphone attached to the robots.

The environment shared by robots and humans were well-suited for this with wide and open space, in which the robots were able to navigate around obstacles and humans.

2.2.11 Interviews

Interviews were a primary method of data generation in this study and provided a way for me as a researcher to gain a deep understanding of the meaning of participants' experiences and point of views. This was essential for gaining a comprehensive understanding of HRC in hospitals, as the interviews are used to explore a wide range of topics, including staffs' attitudes, beliefs, experiences, and behaviours towards mobile robots[112][108,113] [114].

Understanding the perspectives of the hospital staff, the insiders, was necessary to understand the significance of collaboration, routines and work practices. Interviews served as a support to other methods, to gain more comprehensive insights on the field being studied. For example, Barley and Kunda [115] emphasise that some work practices occur too infrequently to be studied solely through observation studies, thus a combination of observation and interviews is optimal in ethnographic studies of work practices. In this case, it would be difficult to gain understanding of the collaboration between hospital staff and robots, without getting the staffs' own notions. Further, interviewing was a valuable tool for understanding attitudes and values, and for gaining insights into what individuals believed they did. However, if one is to understand what individuals *actually* do, rather than what they say they do, it is beneficial to combine the interviews with observational studies, as I did in this study.

Below, the types of interviews deployed in this study, are characterised.

2.2.11.1 Short onsite in-situ interviews

Short onsite interviews are a qualitative research method that involves conducting short, informal interviews with participants in their natural setting. I conducted these to gain a deeper understanding of participants' experiences, actions and interactions when they occurred, throughout their everyday working routines [116]. This type of interviews are often used in observational research, where the researcher wants to gather information about a specific event or activity and are usually brief, lasting between 5-15 minutes [101]. In this study, short onsite interviews were used to gather information about the human-robot collaboration in the given hospitals. I observed and followed mobile robots as they interacted and collaborated with hospital staff in their natural setting and conducted the short interviews with the staff immediately after they had interacted with the robots. I used a set of open-ended questions that were designed to elicit detailed and in-depth responses from the participants, recorded the interviews and made detailed notes of the observations and interactions, during the talk.

Further, the interviews can be characterised as *in-situ interviews,* a similar method, where the interview takes place in the same location or setting as the phenomenon under study. It is used to gather data in a natural setting where the participants are in their usual environment and is often used in ethnographic research. Both short on-site interviews and in-situ interviews were used to gather data in the natural setting, the hospitals, and context of the research, the working lives of hospital staff and mobile robots collaborating, which can provide a more accurate and detailed understanding of HRC in this type of natural setting [117][118] .

2.2.11.2 Expert interviews

Expert interviews are a qualitative research method that involves conducting in-depth, semi-structured or unstructured interviews with individuals who have specialized knowledge or experience in a particular field [114]. The method allows researchers to gain an understanding of the perspectives, opinions, and experiences of experts on a particular phenomenon. In this study, expert interviews were used to gather information about the local collaboration between hospital staff and mobile robots in the given hospitals. The interviews were conducted with respectively kitchen managers (in Study I), technical staff (Study II) and a Technical Manager (Study III). I conducted several interviews with them, as I both sat down and had a talk with them, based on a semi-structured interview guide, but also interviewed them onsite during guided tours they facilitated. Last-mentioned were very free, unstructured and based on what they showed me during the tour, rather than an interview guide. Both the 'sitting down'-interviews and the onsite in-situ talks were open, allowing the experts to provide detailed and in-depth responses and descriptions [112][108,113] [114].

The data collected through expert interviews were analysed using a qualitative content analysis approach [119]. The transcripts were coded and grouped according to themes that emerged from the data. Further, I combined the data with that from other data sources, such as observations, to improve the validity of the findings and make my understanding more comprehensive.

2.2.12 Guided tours

The method of guided tours was utilised in this research project to gain further insight into the collaboration between mobile robots and staff in Danish hospitals and to see, from the participants point of views, sites of their hospitals deemed significant by them. Guided tours are a qualitative method used to collect data through the observation of individuals as they navigate through a specific location or setting – usually combined with explanations. I was taken on guided tours by respectively kitchen staff and technical staff, who guided me through the hospitals, showing me where they were collaborating with the robots and where the robots operated on their own. During the tours, I tried to understand how hospital staff interacted with, and made sense of, their surroundings and gain insights on their notions of having robots in these settings [120,120,121].

The guided tours served to deepen the relationship between me, the researcher, and the participants, allowing for a greater understanding of the nature of roles, setting and the structure and content of the tours. During the tours, both I and the informants took on roles other than those typically associated with interviews, as the informants took lead in the inquiry, determining which areas of the hospital and specific objects to view, showing me around the hospital and discussing their experiences with robots. The power of the event dynamically shifted from that of an interview to that of two individuals, with mutual interests, sharing an experience [120,120,121].

The hospital sites provided powerful environments for relationship building, as the tours took place in a (for the hospital staff) familiar setting, where they felt at ease. The tours were deliberately crafted to be informal and adaptable, thus contributing to the qualitative nature of the inquiry. A fixed, predetermined set of questions was not established, allowing the conversation and exchanges to flow freely and completely on the informants' premises. This loose structure led to interesting talks that included topics that may not have otherwise been raised in the interviews - and the personal nature of the tours allowed me to see both the robots and the hospital through the hospital staffs' eyes. In some cases, the themes and insights gained through the guided tour were further explored in follow-up interviews, consisting of expert interviews and short, on-site in-situ interviews with hospital staff, both kitchen staff, kitchen management (Study I+II) technical staff (Study II), Technical Manager (Study III) and hospital laboratory staff (Study III).

The method was used with the aim of gaining further insights into the hospital staffs' personal associations with their work environment inhabited by robots and the interaction and collaboration with them. The tours provided opportunities to observe the ways in which hospital staff engaged with the robots and experiences that held significance for them, allowing me to explore their perceptions, opinions and thoughts of collaborating with robots, and gaining a sense of the features of the hospital setting, that held individual appeal [120,120,121].

2.2.13 Shadowing

Another method for collecting data in this study, was shadowing. Shadowing is a qualitative research method that involves closely following and observing an individual or group in their natural setting, without their knowledge or participation. The method allows researchers to gain a detailed understanding of the participants' actions, interactions, and experiences in the context in which they occur [108]. The method was applied to scrutinize the robots' work and collaborational efforts, and to view hospital staff and hospital through the sensors of the robots, which were extremely meaningful experiences. Shadowing the robots, I walked along them/behind them or sat on a spot near them, and I observed them as they drove, standed still and interacted and collaborated with humans around them. In some cases, when I walked along the robots, people would approach me and ask, if I was walking a dog; if I was educating the robots to work or if I was the one controlling the creature. For days, I followed robots around the long hospital hallways in Sønderborg, Aabenraa and Odense, observing what they did, when they did what they did. I followed and observed the robots as they interacted with hospital staff and surroundings in their natural setting and made detailed notes of the observations, including the context, robots' actions, and the hospital staffs' responses.

Video recordings were also made of some of the robotic actions as an additional data source. The observations were coded and grouped according to themes that emerged from the data and analysed using thematic analysis, to identify patterns and themes [122]. Shadowing is considered a valuable technique for gaining an in-depth understanding of a phenomenon of interest in its natural setting and allows the researcher to observe participants in their natural environment. However, it's important to note that the method may be criticized for its lack of participant consent and potential, but in present case, shadowing mobile robots, it did not seem to be an issue [108]. Further, I am not completely sure to what extent, the robots I shadowed, were unaware of my presence, as I at times happened to interfere with their space, getting too close to their sensors, which made them stop.

2.2.14 Ethics in fieldwork

When doing fieldwork, the relationship between me (the researcher) and the hospital staff and the robots (the participants), was dynamic, as I was often closely immersed in the working lives and activities of the participants. I tried to get close to the routines, tasks and dynamics of hospital staff and mobile robots, and activities between them, with the goal of understanding how they did what they did. This type of work can be perceived as an invasive way to conduct and calls for ethical codes and principles, to aid the researcher reflect on - and practice - ethical research behaviour [85].

The first step in the process of reaching an ethic for fieldwork is to consider what is characteristic of the relationship between researchers and the explored, when it comes to fieldwork. Firstly, the researcher compared to many other types of research has limited power, participants can freely leave the scene and they usually approve of the researcher's presence. Secondly, it is usually the participants who control and manage the specific setting in which the researcher is present. The researcher is thus on unfamiliar ground. Finally, there is an interaction process where researchers and participants mutually affect each other, producing a certain unpredictability [85]. Across different codes of ethics, there is a general consensus on certain principles.

These are illustrated in the figure below.

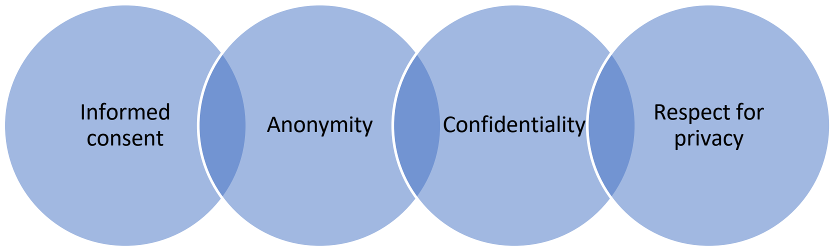


Figure 16 Ethical principles [85]

- Informed consent: Research projects should not be conducted without the consent of participants. Informed consent requires participants to have a clear understanding of the research purpose, procedures, and potential consequences of participation.
- Anonymity: Anonymity ensures that participants cannot be recognized or identified in public based on their involvement in the research project. Protecting participants' identities prevents potential negative consequences resulting from their expressed views or behaviours.
- Confidentiality: Researchers are responsible for safeguarding the privacy of participants by ensuring that collected information remains confidential. Personally identifying information should be kept secure and destroyed after the research project is completed
- Respect for privacy: Researchers should respect the boundaries of participants' privacy. This includes obtaining permission before intruding on private areas or accessing personal information. Respecting privacy helps maintain trust and ensures participants' comfort and well-being during the study [85].

In present PhD study, the participants orally consented to take part in the research. To ensure the participants anonymity, their identities are protected by various methods such as blurring their faces in images, avoiding the display of pictures that could lead to identification, and anonymizing their names. However, the expert participants were asked if their names ought to be mentioned in the dissertation, in research publications and in notes. The ones who consented, are mentioned by name. The anonymity measures are taken to safeguard participants' privacy and prevent their recognition or identification by others. These practices help shield participants' identities and prevent potential negative repercussions resulting from the expression of their views or behaviours during the research. This may aid in maintaining trust and ensure participants' comfort, trust and well-being throughout the study. It's important to note that some participants chose to provide explicit consent for their names to be used, acknowledging their willingness to be openly associated with the research. In such cases, their identities were not anonymized. This demonstrated a conscious decision on their part to be identified and acknowledged within the study. The names of the hospitals, wards and places are not anonymised.

These ethical codes can serve as a guide for researchers when making decisions and choices that have consequences for participants in research projects. However, codes cannot stand alone as a guide for ethical issues in research. There will necessarily be a range of questions and exceptional cases where codes do not provide clear answers, where multiple answers are possible, or where codes outright prevent research. Codes are general and context-independent, therefore, it is necessary to supplemented them with researchers' own reflections and considerations, before implementing research that impacts participants. From formulating the research question to the concrete way of interacting with participants, to the final presentation of participants' behaviour, culture, ideas, or feelings in final reporting. For example, if researching motorcycle gangs, hooligans, neo-Nazis, lodges, or other similar subcultural environments, the researcher's presence may be rejected by participants, as the researcher may be suspected of revealing illegal activities or compromising the group's security [123].

2.2.15 Scoping review

As outlined in paper IV, a scoping review was conducted with the aim of scrutinizing the nature of research of human-robot collaboration in hospitals and examine recent research within the field. The scoping review was conducted to gain an overview of the activities within the field, detailed insights to existing findings and to examine newer point of impact of HRC in hospitals. The scoping approach facilitated a comprehensive examination of various studies, providing a more comprehensive understanding of the collaboration between humans and robots in hospitals. In light of this, a systematic review, which focuses on evaluating and ranking the quality of existing knowledge in a field, was deemed less appropriate. The study adhered to the PRISMA-ScR standards as a framework [4]. Further details regarding the method and execution of the study can be found in Paper IV.

3 THEORY AND CONCEPTUALISATION

This chapter encompasses a range of theoretical frameworks and conceptualisations providing the different lenses the findings of this study will be seen through, in the Discussion chapter. The lenses will be used for *zooming in and out* [124] on the research findings, analysing and interpreting the multifaceted dynamics of HRC in hospitals, providing a comprehensive understanding of the interplay between humans, robots, and the broader socio-technical context, in which they work together. Further, the perspectives will be used to analyse the constitutive role of practices in the phenomena occurring in the three hospitals and serve as analytical tools to unravel the complexities and uncover valuable insights into the implications and challenges of integrating robots into the wild to perform tasks for efficiency and relieving purposes.
The conceptual and theoretical frameworks consist of four key components each. The first component focuses on human-robot collaboration and interaction, encompassing relevant studies in the field such as robots in real-world settings and the phenomenon of humans not using technology. The second component revolves around the relationships and interactions between humans and technology, incorporating mediation theory and the social construction of technology. The third component delves into the realm of work, exploring practice theory, the transformative role of robots in work environments, computer-supported cooperative work (CSCW), articulation work, and the interplay between plans and situated actions. The fourth component revolves around a change application model known as the Leavitt diamond model. These frameworks collectively form the basis for comprehending the intricacies of human-robot collaboration as elucidated in the Findings section.

3.1 Human-Robot Interaction

3.1.1. Defining human-robot interaction

In order to comprehend the concept of Human-Robot Collaboration (HRC), it is crucial to first understand Human-Robot Interaction (HRI). HRI is a multi-disciplinary, emerging research field concerned with studying interactions between humans and robots. HRI has roots in Computer Science, Artificial Intelligence, Human-Computer Interaction (HCI), Robotic Engineering, Natural Language Processing, and Computer Vision. It is also related to Electrical, Mechanical, Industrial and Design Engineering. Further, HRI originates from Social Sciences, studies of Human Factors, Psychology, Cognitive Science, Communications, Sociology and Anthropology. Finally, it is associated with Ethology, Ethics, Linguistics and Philosophy in Humanities [38].
The definition of HRI varies. Feil-Seifer and Mataric who has researched ethical principles for assistive robots, view HRI as an interdisciplinary study of the dynamic interaction between human beings and robots [125]. This interaction refers to the process of working together to achieve a common goal. This, while Goodrich and Schultz who in 2007 published a literature review that identified key themes in HRI, has defined HRI as a field of study that is dedicated to understanding, designing, and evaluating robotic systems for use by or with humans [37].

HRI is a field of study that examines how robots function and how they can be effectively used in tasks involving human beings, and one of the core focus areas are how humans and robots interact through various tools, including visual displays (such as graphical user interfaces or augmented reality interfaces), gaze and gestures (such as hand and facial movements), speech and natural languages, physical interaction, and haptics. A goal within HRI is to make these forms of interaction between humans and robots as natural as possible [38].
HRI is a wide research field which has been applied in several areas such as entertainment, military, search and rescue missions, education, communication and healthcare. The adoption of human-robot interaction in healthcare is gaining traction due to factors such as the growing number of vulnerable populations, rising healthcare costs, and the shortage of qualified healthcare professionals [39].

3.1.2 Types of human-robot interactions

HRI is not limited to focus on 1:1 interaction between a human and a robot, but also encompasses teamwork; one human and multiple robots; multiple humans and one robot; human team-robot team; human team-multiple robots; multiple humans-robot team [126]. Further, the robots can be both different types of robots or the same type of robots [37]. The interaction between humans and robots can take a variety of forms but common for all of these are that the proximity of the human and the robot has influence on the interactions [37]. Consequently, human-robot interactions can be divided into two categories: remote interactions and proximate interactions. In the remote interactions, the humans and the robots are not necessarily physically together in the same location but can work together from a distance. This is for example the case when robots are used in space missions: the spatial separation has influence on how the human and the robot interact with each other. In the proximate interactions, the parties are located near each other in a shared environment and collaborate close to each other. This is for example the case with mobile robots in hospitals, where the robots are running in human-inhabited environments [37].

3.1.3 Roles in human-robot interaction and human-robot awareness

Besides from the types of interactions within HRI, there are also different types of interaction roles the human and the robot can fulfil in their interaction. Goodrich and Schultz have on the basis of a taxonomy developed by Scholtz, identified the most frequent used roles for humans in HRI. The identified roles and their influence on interactions in practice are outlined in the table below.

Table 6 Human roles in human-robot interaction [37]

Human role	Description
Supervisor	The human takes on the role of a supervisor, overseeing the robot's activities. This includes t asks such as monitoring, controlling, and evaluating the tasks performed by the robot.
Operator	The human acts as an operator, responsible for controlling the robot and having knowledge of its location, actions, and the environment it operates in. The operator is accountable for the robot's behaviour and ensuring its proper functioning.
Mechanic	The human assumes the role of a mechanic, involved in programming the robot and being responsible for making changes to its hardware and software components.
Team/Peer	Both humans and robots work together as team members towards a common goal. They interact with each other through gaze and gestures, collaborating to achieve shared objectives.
Bystander	A bystander's role involves accompanying the robot without direct interaction. Although not actively engaging with the robot, the bystander possesses knowledge of the robot and its behaviour to understand the outcomes of the robot's actions.

These roles shape the dynamics of human-robot interactions in practice and highlight the various ways in which humans engage with robots in HRI [37]. In order for HRI to be successful, the human as well as the robot must hold knowledge about, and be aware of, each other. This is referred to as HRI awareness and encompasses the human's understanding of the robot's location, tasks and activities, status and environment; the robot's knowledge of the human's commands that are crucial to point the robot's location, tasks and activities, status and environment the robot operates under and in [126].

Table 7 Types of awareness in human-robot interaction

Awareness Type	Description
Human-Robot Awareness	The human collaborating with the robot possesses knowledge about the robot's location, tasks and activities, status, environment, surroundings, and identities. This awareness enables effective collaboration and coordination between humans and robots.
Human-Human Awareness	Humans collaborating with fellow humans hold knowledge about each other's location, tasks and activities, status, environment, surroundings, and identities. This awareness is essential for human-human collaboration within the context of HRI, facilitating effective communication and coordination.
Robot-Human Awareness	Robots possess knowledge about the instructions and commands provided by humans to perform their tasks and activities. This awareness allows robots to understand and respond to human instructions, enabling efficient interaction and cooperation between humans and robots.
Robot-Robot Awareness	Robots have knowledge of the instructions given to them by other robots. This awareness enables coordination and collaboration between multiple robots, allowing them to work together to achieve shared objectives and carry out complex tasks.
Humans' Overall Mission Awareness	Humans possess knowledge of the overall goal of the mutual activities carried out by both humans and robots. This awareness ensures a shared understanding of the mission's objectives and facilitates coordinated efforts between humans and robots towards achieving the desired outcomes.

These types of awareness, as identified by Drury et al, highlight the different levels of knowledge and understanding that humans and robots have in HRI settings, and how this awareness contributes to effective collaboration and goal achievement [126].

If the parties does not hold awareness of each other, it will reduce their level of interaction and reduce their shared performance in a given, common task [127].

3.2 Human-Robot Collaboration

3.2.1 Defining human-robot collaboration

The research field Human-robot collaboration (HRC) is situated under the umbrella term HRI, comprising classical robotics, cognitive sciences and psychology. The involvement of multiple disciplines is essential to comprehensively understand and the elements in HRC, comprising the types of interaction where humans and robots work together towards a shared objective. Hence, HRC is concerned with how humans and robots are working together on different tasks, aiming at reaching a common goal [80]. HRC pertains to the implementation of collaborative robots, which are specifically designed to work alongside humans and share tasks with them. The standard ISO/TS 15066 [128] provides a definition of a collaborative robot as "*a robot intended to physically interact with humans in a shared workspace*." This is in contrast to traditional industrial robots that are designed to operate autonomously and in segregated spaces. Collaborative robots (cobots) can serve various functions, ranging from autonomous robots that work together with humans in an office environment and can request assistance, to industrial robots with their protective guards removed. The purpose of collaborative robots is to assist humans in their work. However, the implementation of HRC brings about several concerns, particularly in the areas of safety, communication, task organisation, social-related aspects, and psychological aspects [80]. When it comes to safety, working in proximity to robots without any physical barriers may pose new risks to humans. Various approaches have been proposed in prior research to detect the positions of humans and robots, preventing collisions and ensuring a safe co-existence [129]. Several methods have been proposed to ensure safety in HRC, such as continuous 3D image processing or using inertial motion capture suits to detect the position of humans and robots and avoid collisions. To facilitate the implementation of HRC in industrial settings, health and safety regulations have been updated, including ISO 10218-2 and ISO/TS 15066 [128]. Researchers have also investigated how to perform tasks with collaborative robots and how to instruct them. HRC has been studied in various tasks, such as pick and place, assembly, transportation, and 3D printing [38].

One of the major challenges of HRC is to create robots that enable a safe coexistence and a seamless interaction with humans [80]. This necessitates that collaborative robots possess at least a basic degree of autonomy and potentially display initiative. The term "collaborative robot" or "cobot" was first introduced in 1996 by Colgate et al. [130]. In their study, a collaborative robot was defined as a robotic device that collaborates with a human operator in manipulating objects. Specifically, collaboration was perceived as a type of assistance that guided and restricted some of the human's movements in certain operations. While a major focus in HRC is the collaborative process between humans and robots, the concept behind HRC is to leverage the unique strengths of both parties. Humans possess inherent flexibility, intelligence, and problem-solving skills, while robots offer precision, power, and repeatability [128]. When humans and robots collaborate on shared tasks, they can improve the quality of labour, by doing more qualified and effective work, because the automated and accurate from the robot is combined with the flexible, creative and understandable from the human [131].

The advantage of humans working with robots is that each part can perform what they do best: the robots perform repetitive or dangerous tasks, while humans perform more complex steps and define the overall tasks of the robot, since they are quick to recognize errors and opportunities for optimization [132][133].

The collaboration between human and robot is a result of new applications for robots that requires them to engage in working alongside humans, as members of a human-robot team. This is, for example, common in industry settings where robots are designed to engage in close work relations and physical interaction with the human. But robots have moved out of the industrial manufacturing environments, and the laboratory settings where most research on robots have been conducted, and into more complex settings, such as homes, medical, care, educational and defence settings [134] [135].
According to HRC researchers from MIT Media Lab, efficient HRC encompasses the collaboration to take place in a shared environment, where human and robot must participate in joint activities, shared work tasks, and joint intentions to fulfil tasks [136].

3.2.2 Defining collaboration

Over time, the term ”collaboration” has been defined in various ways and sometimes used interchangeably with cooperation in literature, however it is important to recognize that they can have distinct meanings. Kozar has emphasised the contrast between these terms by presenting the definitions provided by various authors. While the distinction between cooperation and collaboration is not clear in terms of HRC, it has been deeply reflected upon in other fields. Within education, researchers such as Dillenbourg et al. (1996) and Roschelle and Teasley (1995) emphasise the importance of distinguishing between cooperation and collaboration. While cooperation is often defined as "working together to accomplish shared goals" [137], collaborative learning is described as "a method that implies working in a group of two or more individuals to achieve a common goal, while respecting each individual's contribution to the whole" [138]. Roschelle and Teasley (1995) further differentiate cooperative work as a task that is divided among participants, where "each person is responsible for a portion of the problem solving," and collaborative work as "the mutual engagement of participants in a coordinated effort to solve the problem together" [138–140]. Nevertheless, collaboration necessitates knowledge sharing, which entails direct interaction among participants through negotiations, discussions, and considering each other's viewpoints [80). As a result, in contrast to cooperation, collaboration entails a more intricate form of interaction and necessitates the fulfillment of additional requirements to be achieved.

The key distinction between cooperation and collaboration lies in their approaches to group work. Cooperation focuses on working together to create an end product, where participants do their assigned parts separately and bring their results to the table. In contrast, collaboration involves direct interaction among individuals to produce a product, requiring negotiations, discussions, and accommodation of others' perspectives [138–140]. These elements complexes collaboration further than the case is, in cooperation. Collaborative learning leads to deeper information processing and more meaningful psychological connections among humans, compared to working individually [141]. While collaboration aims to create insights during discussions and move parties closer to understanding alternate perspectives, humans can build new understanding by challenging others' ideas and defending their own, resulting in a product that is different from what any individual could produce alone [142][143]. Kaye (1992) suggests that the integration of different perspectives, talents, and ideas, combined to create new insights or products, is the primary criterion for successful collaboration, setting it apart from individual contributions [143]. A crucial aspect of collaboration is that all participants must make a relatively equal contribution to the task [143]. However, collaboration can be complex to achieve, due to complexity [144][141]. The complexity of collaboration is partly due to the requirements for structural, interpersonal, and cognitive demands on individuals, in comparison to cooperative activities, which can be characterised as more passive [142]. Therefore, it is crucial to understand the key differences between cooperation and collaboration when planning for effective team activities. For robots to engage in collaboration with humans, robots will need to have at least a minimum form of autonomy and possibly show initiative [133]. Within the realm of HRC there exists a notable ambiguity surrounding the distinction between cooperation and collaboration when it comes to the involvement of robots. The term HRC is often used as a broad and all-encompassing label for the various types of relationships between humans and robots within a work setting. These relationships can range from mere coexistence and contact to true cooperation and collaboration. This will be further discussed in the Discussion chapter.

In the following sections, the varying aspects of HRC are delved into, analysing the diverse working relationships between humans and robots, and examining how these manifest in real-world contexts.

3.2.3 Human-robot teams

When humans and robots are collaborating on a common task, they can join forces and form a team. A team is defined as "*a small number of partners with complementary skills who are committed to a common purpose, performance, goal, and approach for which they hold themselves mutually accountable*" [145]. In human-robot teams, the partners are humans and robots, committed to reach a common goal by collaborating [146].

Early studies investigating working relationship between human and robot has centred around the robot as the human's tool to reach a goal [147]. Later, the perspectives have shifted to focusing on the peers as a team and the qualities of these [148]. Laboratory research has found that in order for the teamwork to be meaningful, the robots must be given more freedom and function as partner for the human, not a tool. Ideally, both the human and the robot must be able to detect own and each other's' limitations and act upon these, for example the robot must be able to adapt and adjust its behaviour to meet the variable human responses – and the human must be able to fluidly and dynamically entrust the robot more complicated tasks than traditionally [149]. This will make the human-robot collaboration more natural, balanced and direct: less rigid, less defined and less predictable [148].

There are certain key characteristics that makes up the foundation for efficient human-robot teamwork which are respectively shared activity, joint intention and common ground.

3.2.4 Shared Activity

According to Hoffman and Breazeal, shared activity is one of the basic elements in efficient human-robot teams. Shared activity is an interplay of actions that parties of a team perform, in order to reach a shared goal, by following a common plan. Hoffman and Breazeal draw upon the work of Bratman's detailed analysis of Shared Cooperative Activity that describes how shared activity requires a mutual responsiveness, common commitment to the activity and pledge to support each other. These elements guarantees the joint activity to be robust, even under complex circumstances and in changing environments [150].

3.2.5 Joint intention

In order for the collaboration between the human and the robot to be efficient, a plan for both of them is required. In HRC it will usually be the human who defines the tasks and the goals for these, while the robot must take on the human's intentions and assist the human, in order to reach the stated goals. By doing so, the parties acquire a joint intention to reach their goals [146]. According to Bauer, Wollherr, Buss 2007, HRC is achieved through the human and the robots' individual actions and aids towards fulfilling the joint intentions or actions. When the parties have a joint intention, they have a common goal – and will have to plan their individual actions in accordance with each other. To be able to plan their actions, the human and the robot will need information about the actions and intentions of each other, as well as they will need knowledge about each other's abilities and the possibilities in their surroundings. When the parties hold that knowledge, they will be able to choose appropriate actions to take, in order to aid in fulfilling the joint plan and make HRC efficient [146].

3.2.6 Common ground

Another key characteristic of efficient human-robot collaboration is that the parties have common ground. Common ground is a process of coordinating between parties, in order to reach a mutual understanding, based on shared knowledge, beliefs and assumptions between these parties [151]. According to Herbert Clark and Deanna Wilkes-Gibbs, common ground is a requirement for efficient collaboration, since it aids collaborating parties to know what their peer needs and how to communicate to each other in a meaningful way [152]. At the beginning of a human-robot collaboration, the common ground can be minor, as the human and the robot only hold a small amount of understanding about each other. This is likely to increase over time as the collaboration unfolds. In order for the peers to obtain a better understanding of each other, coordination indicators/devices can be used in the collaboration. These can for example be a flashing lights or warning sounds [147]. Yet another way of increasing common ground is joint closure, where the collaborating parties tries to establish a common belief in having completed and succeeded in their joint actions [147].

Having established a conceptual understanding of human-robot collaboration and its various dimensions, it is crucial to delve into the practical realities of these interactions.

3.3 Related work: robots in the wild

As the field of robotics continues to advance, researchers have increasingly turned their attention to exploring the capabilities and applications of robots in natural and unstructured environments: "the wild”. In the following, related work that focuses on the deployment and operation of robots in these challenging and unpredictable settings, are explored.

Research on human-robot collaboration in natural work settings has shown how organisational elements impact humans and robots, and how human perceptions of robots differs, because of various influences within the working environment. Mutlu and Forlizzi [153] have researched mobile robots in hospitals and found that different hospital wards perceived the same robot in different ways, due to varying levels in toleration of disturbances within their working environment. Accordingly, human perception of robots in a workplace changes over time, as the human workers gets more familiar with the robots. This is seen in an ethnographic study conducted by Ljungblad et al, [154] who have researched hospital staffs’ reactions to a robot at a hospital, and on the basis of this, proposed four different perspectives hospital staff can take on, when they perceive a robot. These perspectives might change over time, for example as the personnel gets involved in closer working relationship with the robot and their intimacy changes [154].
Related work presents challenges of robot adaption and argues that such RITW-studies will enhance understanding of how humans and robots adapts to each other, in practice. This is on the verge of becoming a highly important element of HRI research, as robots are leaving development environments and enter the social world. It is of great importance that both humans, who are to benefit from interacting with robots, and the context in which the peers will interact in, must be emphasised, when robots are developed. This, because roboticists and designers are unable to control the robots and the adaption of them, when the robots have left the development environments and deployed into practice [76]. The large part of research on human-robot interaction outside laboratory, industry and development/design settings, rather in the natural settings, evolves around robots operating in peoples’ home. Such studies are e.g. concerned with users’ long-term use of robots that have become part of peoples’ everyday lives and how they have become so. A theme that is recurring in these studies is the novelty effects of having robots around. Studies of robots’ novelty effects and users’ long-term use of household and entertainment robots, such as robotic toy animals, in their home, have shown that the use patterns of robots change over time [155] [156]. One of the challenges within this is that the novelty effect that stimulate users’ initial practice around the robots, will vanish after a short period of time and users will slowly start ignoring the robots. In consequence, research on human-robot interaction in natural environments, is also concerned with understanding what engaged humans to continuously interact with robots in their environment, even after the novelty effect has worn off.

In addition, the composition of an environment influences how the humans within this environment, use and experience a robot. This is for example seen in the work of Forlizzi 2007 through an ethnographic study of consumer robots in homes, researched the social impacts of robots and found that a robotic vacuum cleaner changed peoples' cleaning activities and routines, it affected people and had an influence on who was responsible for the cleaning tasks, it affected the nature of cleaning tasks and not least, the vacuum cleaner robot affected the home ecosystem; the social and cultural context of using the robot, including how activities, people, robots and environment had an impact on the ecology within the environment [157]. In 2013, Fink et al [158] completed a 6 month ethnographic study of domestic service robots entering peoples' houses, in order to understand the long-term adoption process, while considering the users (people living in the house) and their needs; the features of the home environment; and the social aspect of the home. Through their study, they were able to see how robots in homes affected people to adjust their homes in accordance with the robot: people would reorganise their furniture and remove stuff from the floor, making the environment easier for the robot to navigate in. A similar study was conducted by Sung et al 2007 [159]. By studying robotic vacuum cleaners they found that people tend to assign their household robots names, identities or/and personalities, leading to greater acceptance of robots in homes. They suggest that the humans and robots are emotionally attached to each other and engaged in an intimate relationship, expressed through people feeling happy towards the robotic vacuum cleaners; people promoting and protecting the vacuum cleaner; and lifelike associations and engagement with the robots, such as ascribing the robots with personality for example through names [159]. Ascribing human characteristics or behaviour to a robot can be characterised as anthropomorphism, which has a significant influence on HRI, as robots take on more social roles such as assistants and companions [160–163]. The perception of human-likeness plays a vital role in the realm of HRI, which is particularly significant because human attributes often serve as guiding principles in the design of robots [160–163].

Research and development in robotics have focused on enabling robots to communicate and behave more like humans, aiming to facilitate their utilisation [34,164]. This pursuit in robot design reflects the desire to create engaging and interactive experiences for users. By incorporating familiar social cues and communication patterns, robots can establish a sense of connection and understanding with humans, fostering more enriching human-robot interactions and relationships. However, it is crucial to ensure that the robot's appearance aligns with its capabilities. An overly anthropomorphic appearance may create expectations that the robot cannot fulfil. For example, if a robot has a human-shaped face, users may expect it to listen and communicate. To avoid disappointment, developers must carefully consider the level of anthropomorphism in their robots [160–162,165].

Transitioning from the exploration of researching robots in the wild, the focus now turns towards a phenomenon that is intricately intertwined with human-robot interactions: the concept of human non-use of technology.

3.4 Related work: Human non-use of technology

Human non-use of technology delves into the reasons and implications behind the limited adoption or resistance towards technology by individuals or groups. However, there is a lack of research on why individuals decline using technology in general and robots in particular, resulting in a weak understanding of the underlying reasons for non-use. De Graaf et al [166] have researched human reasons for refusing or leaving robots behind and found that the challenge for robot designers is to create robots that are enjoyable and user-friendly in the short-term, while also being functionally relevant to keep users engaged in the long-term. The role of users has been the focus of increasing attention in technology acceptance literature, as their role is critical, when trying to comprehend the cultural and social contexts of acceptance. In addition, knowledge of user preferences, perspectives and behaviour are vital for developers to incorporate into their designs [166]. This perspective acknowledges that users play a significant role in shaping technology. Understanding human perceptions, expectations, and experiences of socially interactive technologies in a real world setting over an extended period is essential to inform the design and acceptance of these technologies. Consequently, it is imperative to conduct research that examines its long-term acceptance of robots 'in the wild'. Over the past few decades, a significant amount of academic research has highlighted the widening gap between technology users and non-users, commonly referred to as the digital divide. This issue has been extensively explored in numerous studies [167–171]. De Graaf has proposed that the evaluation of technology users should extend beyond those who adopt and utilise the technology to include the less visible group of individuals who decline or abandon its use. Understanding the reasons underlying refusal or abandonment of technology can provide valuable insights that can inform the development of new technologies and applications, thus benefiting potential end-users. Consequently, individuals who choose not to use robots are equally important as those who embrace them. In HRI the majority of research focuses on short-term interactions or responses to written or visual stimuli and only a minority of studies examine users' behaviours toward robots after initial exposure. However, the phase after initial use is critical in determining whether users will adopt and continue using a technology or reject and discontinue it. Examining human-robot interaction in real-world contexts over a more extended period provides a unique opportunity to evaluate acceptance or non-use of robots. However, the few existing longitudinal studies of HRI in the real world, have revealed that many robot systems failed to engage their users in the longer term. The work of De Graaf et al showed that different non-users of robots presented distinct motivations and justifications for their refusal, denial, or cessation. For some participants, the primary reasons to discontinue using a given robot were related to their perception of the robot as less enjoyable, too intelligent, or autonomous, and less useful. This raises questions about the long-term goal in robotics to develop fully autonomous machines, as some people perceive robots as tools that should only perform tasks imposed by their owners. It is also possible that people are still unfamiliar with the intelligent and autonomous behaviour of machines, and that familiarity could decrease people's aversion to artificial intelligence. Other participants primarily stopped using the robot because they had expected more sociable behaviours from the robot, or because they had replaced the robot's functionalities with another device since the robot was unable to adapt to their needs for personalization [166].

Building upon the exploration of related work, the next section delves into a theoretical perspective providing a deeper understanding of the dynamics between humans and technology.

3.5 Human-technology relations and interactions

When exploring the interactions between humans and technology, the works of Verbeek is crucial to pay attention to. Rather than focusing solely on the technology itself, Verbeek emphasises the importance of studying the interactions that occur between humans and technology [172]. According to Verbeek, interaction translates into “action-in-between”, referring to the dynamics between a human and a technological artifact, illustrating the nature of their relationship: they relate and act upon each other and in between them, a specific type of action takes place. From a philosophy of technology point of view, humans and technologies are not to be perceived as two separate entities with interactions in-between, rather as a mutual shape of each other, within the relationship that develops between them [172].
Verbeek acknowledges that technology always influences human behaviour to some extent, making it necessary to design technology responsibly, desirably, and for the benefit of humans. Furthermore, humans also play a role in shaping technology: instead of being merely objects or tools used by humans, technology is often better understood as an immersion or fusion, where human behaviour is closely integrated with technology. Consequently, technology is not just something humans use, but an active entity that mediates, shapes, and influences human behaviour. In addition, the relationship is often part of a larger dynamic between humans and their world, in which technologies play a mediating role. This means that the design of interactions involves not only designing technological objects for specific interactions but also designing the humans who interact with them. Any technology creates specific relationships between its users and their world, resulting in unique experiences and practices. Consequently, it is crucial for designers of technology to be aware that what they design is not an object, but a relation between humans and the world, shaping experiences and practices. However, technologies are quite often designed with the intention of being used, and as such, the level of interaction quality that humans can have with a technology, is usually evaluated in terms of its functionality and usability. Nevertheless, the relations between technology and humans are seldom characterised as “use” relations. Perceiving technology as a tool reduces the complexity of the role of technology and oversimplifies the relations between humans and technology. Human-technology relations are more complex than just assessing functionality and use [172].

Verbeek distinguishes between three approaches to understanding the relationship between humans and technology: technologies can be viewed as extensions of humans (extension); there can be a dialectical relationship between humans and technologies (dialectics), and human-technology relationships can be analysed in terms of hybrids (hybridity) [172].

3.5.1 Extension
When examining the relationship between humans and technology through the lens of extension, technology is viewed primarily as a tool or instrument that facilitates human activities. It is perceived as neutral and does not actively shape human practices and experiences. Joe Pitt's work on the neutrality of technology is a good example of this approach, where he argues that technology must be viewed as neutral from a moral standpoint to prevent diluting the idea of moral responsibility. Pitt suggests that assigning agency to material artifacts provides an unjustified moral excuse for humans to evade responsibility for their actions. Another form of extensionism is the "extended mind theory" by Andy Clark and David Chalmers, which claims that cognition is not limited to the human mind but also extends to material objects such as agendas, computers, and brain implants [172][173]. They assert that technologies help shape human functioning, making them a part of what it means to be human. However, this approach is a variant of the hybrid approach that will be further elaborated below.

3.5.2 Dialectics
The dialectical approach to human-technology relations presents a contrasting perspective to the extensionism approach. This perspective views technologies as opposing forces that overpower human intentions and alienate individuals from the production process and products. For example, Marxist critique of mechanization highlights the alienation of laborers from production processes and products. Similarly, information technologies are criticized for their impact on human cognitive skills. However, another version of the dialectical approach takes a positive outlook on the tension between humans and technologies. It regards technologies as externalizations of specific aspects of human beings that allow for human development. According to Verbeek, Ernst Kapp's philosophical-anthropological approach to technology posits that technologies are projections of human organs, such as a hammer being a projection of the fist, a saw of teeth, and the telegraph network of the human nervous system. In addition, Wilhelm Schmid argues that as tools progress to machines and automata, human capacities are externalized. Interacting with technologies can, therefore, provide humans with a relation to themselves as well [172].

3.5.3 Hybridity
The hybrid approach challenges both the extensional and dialectical approaches by highlighting the fundamental problem of separating humans and technologies into two distinct spheres. Instead, the intertwining of humans and technologies is best understood through the concept of hybrids. Technologies are not merely extensions or oppositions to humans but are part of human nature, shaping our perceptions, experiences, actions, and ways of living. Technologies mediate our interactions with the world and help to shape how we can be present in the world. In the postphenomenological approach to technology, technologies are seen as mediators that help shape human practices and experiences, requiring designers to not only design products but human existence itself. A responsible approach to this hybrid relationship between humans and technologies requires a thorough conceptualisation of human-technology relations and the role of design in shaping them [172].

3.5.4 Mediation theory

Exploring the mediating role of technologies can be achieved by examining the different types of relationships that exist between humans, technologies, and the world. Verbeek has built upon the works of Don Ihde, identifying where technologies have an impact on human beings and distinguishing the various types of influence they exert on human actions and decisions [88]. As Don Ihde characterise four types of relations (embodiment, hermeneutic, alterity and background), Verbeek adds to the four with the following three types of relations: cyborg/fusion, immersion, and augmentation [88] [172]. The types of relations, purposed both by Ihde and Verbeek, will be outlined below.

Table 8 Don Ihde's four types of relations [88]

Relation	Representation
Embodiment Relation	(Human – technology) world
Hermeneutic Relation	Human (technology – world)
Alterity Relation	Human technology (- world)
Background Relation	Human (– technology – world)

Don Ihde's postphenomenological approach to technology focuses on analysing the various types of relations that exist between human beings, technologies, and the world. Ihde's research delves into how technologies contribute to human-world relations, ranging from being "embodied" and "read" to being "interacted with" and "in the background".

In cases of embodiment relations, technologies merge with a human being to form a unity that interacts with the world. For instance, when we use a phone to speak with others, we consider the phone as an extension of ourselves, rather than a separate entity. Similarly, when using a microscope, we look through it rather than at it. Ihde categorizes this relation as (human-technology) → world. A second way Ihde refers to the relations between human-technology-world is the "hermeneutic relations" as the ways in which humans interpret how technologies represent the world. He uses the example of an MRI scan showing brain activity, and a metal detector beeping to indicate the presence of metal. In this type of relation, humans focus on how technologies represent the world rather than the technologies themselves. This can be diagrammed as "human → (technology - world)". On the third hand, the "alterity relation" involves human interaction with technology while the world remains in the background. Examples include using an ATM or operating a machine. This relationship is a key domain of interaction design and can be diagrammed as "human → technology (world)". Ihde also identifies the "background relation" in which technologies serve as a context for human experiences and actions. This includes sounds from air conditioners, fridges, and notification sounds from cell phones. In this relation, technologies are not experienced themselves, but rather exist as a context for human existence. This can be diagrammed as "human →(technology/world)" [88].

Table 9 Verbeek's three types of relations [172]

Relation	Representation
Cyborg Relation	Human/technology → world
Immersion Relation	Human ←→ technology/world
Augmentation Relation	(Human - technology) → world human → (technology - world)

According to Verbeek, there are several recent technologies that cannot be easily classified into the four relationship categories, for example because some technologies are more intimate than those described by the embodiment relation, while others have a stronger contextual influence than those of the background relation [174]. For example, a brain implant used to treat Parkinson's disease or psychiatric disorders does not simply embody the technology; rather, it merges with the human body to form a new hybrid entity. This type of relationship can be referred to as a "cyborg relation", which can be represented as "human/technology → world". In contrast, some technologies merge with our surroundings to form smart environments that exhibit what is characterised as ambient intelligence and, in some cases, persuasive technologies. In these contexts, technologies are not just passive backdrops for our existence, but rather interactive contexts that detect the presence of people, recognize faces, and provide feedback on behaviour. This immersive configuration can be depicted as "human ←→technology/world". Verbeek characterises this as Immersion relations. Wearable technologies such as Google Glass represent another type of human-technology relationship. They lead to a division of the human-world relationship: on one hand, smart glasses can be embodied to provide a first-hand experience of the world, while on the other hand, they also offer a representation of the world on a parallel screen. This relationship could be termed augmentation relations, which combines an embodiment relation and a hermeneutic relation: (human - technology) → world + human → (technology - world) [172].

3.5.4.1 Mediation

The use of technology impacts human experiences and practices across three dimensions. Technology is not external to human beings but rather, helps define what it means to be human. Technology assists in developing knowledge of the world, moral actions and decisions, and even metaphysical and religious frameworks. For instance, MRI scanners provide neuroscientists with specific access to the brain, obstetric sonography informs ethical decisions about abortion, and IVF reorganises the boundary between fate and responsibility. Technological mediation is an integral part of being human. Therefore, designing technology is designing humanity itself. Since any technology shapes human actions and experiences and can have ethical implications, designers have a significant responsibility to ensure their designs align with ethical standards. Therefore, mediation should be a central consideration alongside functionality, interaction, and aesthetics in the conceptual framework guiding design activities [172]. The theory of mediation suggests that technologies always play a role in shaping human practices and experiences, and we should not attempt to eliminate their impact but rather embrace it. Instead of striving for complete autonomy from technology, we should focus on creating responsible forms of mediation. This requires empowering users, designers, and policymakers to understand, design, and implement technological mediations in a critical, creative, and productive manner. By doing so, we can deal with the hidden powers of technology in a responsible way and develop free relationships with them. It is important to recognize that avoiding technological mediations does not protect human freedom; rather, it is only by dealing with the inevitable mediating roles of technologies in a responsible way that we can achieve true freedom [172].

Mediation theory provides a way to comprehend the interactions between humans and technology and by employing the concept of mediation, we can move beyond viewing technology as solely functional and instead recognize its role in mediating human practices and experiences. Through the use of technology, users engage in a relationship with their environment, and mediation theory can aid in examining the various forms these relationships can take. This includes analysing the points of contact between technology and its user, as well as identifying the specific types of mediation involved [172].

3.6 Social Construction of Technology

The Social Construction of Technology (SCOT) can be described as a social constructivist approach that argues that the social and the technological cannot be separated. Instead, the social shapes the technological: Users influence technology through their usage of it. SCOT is concerned with exploring the social context in relation to a given technology, such as how healthcare professionals influence a health IT system. The founders of this theory, Pinch and Bijker, emphasise that relevant social groups are co-creators of technology. The concept of a relevant social group refers to a collection of individuals who share the same set of opinions about a specific technological artifact. These opinions determine how users employ the technology, making them active co-creators of it.

In SCOT, users of technological products play a significant role. They attribute meaning to technology, find purpose in its use, and have opinions on its design and form, partly based on their specific ways of using it. Users are co-creators of technology in terms of meaning, use, design, and form of a given product. Co-creation occurs through the perceptions and interpretations of different social groups, which SCOT assumes to vary from group to group. Multiple social groups can influence technology in their own ways based on how they use it. Therefore, it is essential to consider technology in the context in which it is embedded, taking into account the social groups (their reality) and their different constructions of technology [175,176].

For example, one group of service workers may have values, procedures, workflows, etc., that differ from other groups of service workers. One group may perceive a technology, such as robots, as functional and meaningful, while other groups may struggle to adopt to it. The various contexts in which technology is employed significantly influence how it is perceived and interpreted. Pinch and Bijker refer to as "interpretive flexibility", which can take on two aspects, as seen in the table below:

Table 10 Types of interpretive flexibility [175,176]

Interpretive Flexibility	Description
Groups attribute different meanings to the same artifact	Regardless of functionality, user-friendliness, size, aesthetics, etc., a technological artifact can always be interpreted differently depending on the context in which it is embedded.
Groups influence the physical design of the artifact	Technological artifacts are constructed based on groups' influence. For example, the final design of a health IT system could result from incorporating input and needs from different groups.

The interpretive flexibility implies that different groups' influences on technological products can be conflicting, leading to disagreements, discussions, and controversies. Technology is entangled in groups' influence, knowledge, and experiences, as well as in society's history and development and consequently, the design of a technological artifact is often the result of events and controversies that have influenced technology in different directions. Controversies often have high intensity in the early stages but tend to decrease over time.

Despite controversies often diminishing over time, there will still be different interests and expectations regarding the final product. Therefore, complete stabilisation rarely occurs, Pinch and Bijker instead discuss degrees of stabilisation. Gradual stabilisation leads to the closure of controversies, issues fading away, and the groups no longer consider them as actual problems. There are two forms of controversy closure, as seen in the table below:

Table 11 Closing strategies [175,176]

Form of Controversy Closure	Description
Rhetorical closure	A group of actors tries to convince the opposing party that their group is right (e.g., that a specific design of an IT system does not pose a threat to the opposing party's values).
Redefined problems	When the technology does not fulfil its original purpose and instead solves a different problem (e.g., when the target audience of an IT system discovers that the system can be used for purposes other than originally intended, benefiting another professional group).

To the social groups, interpretive flexibility, and closure strategies, another dimension can be added: the technological frame. According to Bijker, this concept encompasses the reasons why a social group assigns a particular meaning to technology. The frame can include all the elements that influence the interaction within social groups. Each social group has a technological frame through which they derive meaning from technological products. We, as humans, can bring the technological frame into play when encountering new technology, interpreting it based on our experience with other technologies. However, it is also possible for us to belong to multiple different social groups, thus drawing on various technological frames. New technological frames are established through interaction with the product, and as a result, technological products are assigned meaning based on the users. An individual can vary in the degree of inclusion in the technological frame. Bijker refers to this as the degree of inclusion. The level of inclusion can vary and be adjusted based on human actions, such as the extent to which assumptions, concepts, and methods from the technological frame are adopted. If the degree is high, the person thinks, acts, and interacts to a large extent based on the technological frame(s) they are part of through the social groups they engage with. Conversely, if the degree of inclusion is low, it can indicate a lack of interest, skills, or otherwise limited engagement in the given frame.

SCOT argues that social groups have significant influence on technology and can interpret it in various ways. When multiple groups can influence technology, it is crucial to consider the technology within the reality and context it is a part of. The different influences can lead to controversies that can gradually stabilise the technology. Each social group has a technological frame through which they assign meaning to technological artifacts. Individuals can draw on multiple technological frames and therefore attribute meaning to technology based on their experience with other technologies [175,176].

Having explored the realms of Human-Robot Interaction (HRI), Human-Robot Collaboration (HRC), Robots in the Wild, Human Non-use of Technology, Human-Technology Relations, Interactions, and Mediation Theory, as well as the Social Construction of Technology (SCOT), the focus now transitions to the domain of work.

3.7 Practice theory

Practice theory is a theoretical approach that prioritizes the study of actors' ordinary activities as they unfold in concrete, everyday situations. The term "theory" in practice theory is understood as a general and abstract approach to a field, seeking to understand social phenomena based on actors' actions and activities. Practice theorists, when investigating an empirical field, tend to focus on the lived social lives of actors, involving examining not only routine-based, rule-governed, and institutionalised patterns of action but also situations in which routines are disrupted and rules are not followed. The aim is not only to explain the social activities and work processes of actors based on rules, routines, and institutions but also to investigate how the activity creates and transforms a social order [177]. When contemplating practices, it is important to notice that they are never isolated, but rather exist in interaction with other practices and material arrangements. Social life is interconnected through people's involvement in various practices and handling of different materials. When practices and materials are extensively intertwined, they form bundles of practices, which can be observed in specific contexts. However, practices are not just a sum of actions; researchers must also understand the meaning and direction behind the actions [124,178]. One way to grasp how practices are linked together, is by studying the practical and general understandings, teleoaffective structures, explicit rules, and material arrangements [179]. The content of these concepts is outlined in the table below.

Table 12 Overview of the elements constituting practices [179]

Concept	Definition
Practical and general understandings	Shared knowledge and interpretations among individuals engaged in a particular practice. It encom passes understanding the purpose, goals, and methods of carrying out tasks within the practice.
Teleoaffective structures	The combination of teleological (goal-oriented) and affective (emotion-related) aspects that shape and guide actions within a practice. It includes desired outcomes, motivations, and emotional dynamics influencing how work is performed.
Explicit rules	Formal or informal regulations, guidelines, or instructions that govern behaviour and decision-making within the practice. These rules establish a framework for consistency in task execution.
Material arrangements	Physical or tangible elements and resources involved in the practice. This includes tools, equipment, technologies, spatial arrangements, and other material components that facilitate or impact work execution.

Practice theorists argue that individuals, while initially acting spontaneously, coordinate their actions within social orders through the practices they engage in. Anders Buch uses the example that participating in a practice can be likened to walking in step; it is not flags, traditions, paradigms, or tacit knowledge that concretely coordinate a group of soldiers to march in unison. The soldiers also do not read and interpret a metronome (a rule) that instructs each soldier on how to maintain the pace. Instead, each soldier is accountable to the rest of the group (and the sergeant), and they continuously adjust and adapt their steps to find the collective pace. If a soldier stumbles and falls out of step, it is expected that they will strive to get back in sync by observing and adjusting their steps to match the group's pace. Thus, the pace (the practice) is both created through the actions of the actors and something that individual actors must conform to It is precisely these insights that practice theorists like Schatzki seek to reconcile. For the practice theorist, the overarching question is therefore how to explain how individuals, who act spontaneously and freely as a starting point, nevertheless coordinate their actions in social orders. The answer, according to practice theorists, is that it is the practices of the actors that create this order [124].

Practice theorists advocate for the notion that human activity is deeply embedded in the context of everyday life, characterised by its physical, temporal, and spatial dimensions. Such activities are intricately intertwined with the material world in which they occur. Hence, it becomes essential for practice theory to contemplate the ways in which the tangible physical and material environment of human activity influences, encourages, constrains, or obstructs the execution of actions. Practitioners of practice theory do not want to understand actors as homo economicus (the autonomous, rational, and calculating individual who pursues their own goals and projects detached from traditions and social ties) nor homo sociologicus (an entirely controlled and rule-following puppet who blindly allows culture to dictate without any agency of their own). Rather, practice theorists conceptualise the acting human as homo practicus, an actor who is guided by, and also guides, social practices. In practice theory, knowledge is considered something attributed to individuals and is continually generated, questioned, and reconstructed through concrete activities and practices. It is through engaging in these tangible actions and practices that knowledge emerges and evolves.

Similarly, practice theorists follow Wittgenstein's analysis of meaning from 1953, which states that meaning is established through the way we use language, and there is no other meaning than the one manifested through concrete uses of language. Hence, knowledge, meaning, and language are not abstract and non-material but rather something that manifests itself through human actions and practices. Practice theory also emphasises power relations, interests, negotiations, conflicts, dominance, inclusion, and marginalisation as important elements in the dynamics within and between social practices [180]. Practice theories highlight that actors play an active role in constructing and engaging in relationships with both human and non-human entities. Humans are not separated from the world they live in and do not need to interpret sensory impressions to access it. Instead, the world meets us immediately, and we are familiar with it due to our training, socialization, routines, and way of life [180] [124,178]. Practices are always changing and unfinished, and it is the actors with their agendas and projects that drive them forward and transform them. These characteristics are often closely interwoven in the perspectives and methods that researchers use when studying and analysing social practices, both in terms of how these practices are understood and how they are approached empirically [180] [177].

Different theorists within the practice theory framework place varying degrees of emphasis on specific aspects of the characteristics mentioned above, and they draw upon different philosophical and theoretical traditions to justify and explain their perspectives. In addition to drawing arguments from Wittgenstein's philosophy of language, practice theorists typically draw on and discuss their own methodologies, discourses, and conventions, as well as social learning theory, activity category theory, practical ecology, feminist pragmatism, and actor-network theory, among other [177] [124,180]. Although these various social scientific traditions may not consider themselves practice theorists, they share a common interest in studying social practices and examining how actors reproduce a social order they are a part of—a turn towards practice. Davide Nicolini, one of the authors in this field, suggests that the different theories can be understood in their interrelatedness through Wittgenstein's concept of family resemblance, where many concepts exhibit a network of similarities and overlapping features resembling a family [124,178].

Further, Nicolini proposes an iterative approach for practice-theoretical research, involving zooming in and out on practices to understand their local formation and global dissemination. His framework involves magnifying practice details, switching theoretical lenses, and selective re-positioning to grasp the mutual implications and relationships between local practice accomplishment and the broader textures they create. Nicolini's framework employs sensitising concepts that generate recognisable sets of mediated actions and expressions within a horison of sense and normative concerns. These evolving sets of actions and expressions, formed through the use of various resources, constitute a "practice net" of interwoven and deferred practices.

The framework also recognises the configuration of interests and phenomena like hierarchy, power, and identity within practices. It acknowledges the political nature of establishing and stabilising practices through translation.

Feldman and Orlikowski (2011) emphasise the importance of investigating the why, how, and what of practices within the practice theory framework. The "why" question involves examining the ontological and epistemological status of practice and understanding its role in social life. The "how" question focuses on the dynamics and mechanisms of practices, the relationships within and between practices, and the influences on actors' actions. The "what" question aims to empirically investigate actors' everyday activities, routines, and improvisations in specific fields [181].

3.8 CSCW

The field of research on collaboration mediated by technology, particularly computer-supported cooperative work (CSCW), is extensive and interdisciplinary. Emerging in the 1980s, CSCW has evolved into a broad area, adopting a multidisciplinary approach, drawing from various research areas, including computer science, human-computer interaction (HCI), sociology, psychology, and organisational studies, to investigate the interplay between technology, social processes, and organisational dynamics. According to Schmidt and Bannon, CSCW is "*a research area devoted to exploring and meeting the support requirements of cooperative work arrangements"* as it addresses questions about the characteristics (and hence the general support requirements) of cooperative work, as opposed to work performed solely by individuals [137]. Schmidt and Bannon explain that this research field encompasses a wide range of topics and approaches and is occupied with how technology can enhance cooperative work among individuals or groups in diverse social contexts. However, CSCW primarily focuses on issues related to the design and use of technologies in social and work settings – including organisations, teams, and communities. A significant area of research has been dedicated to understanding coordinated practices in the workplace [182] which has shed light on assumed models of technology use [183] and the importance of systematic studies of real-world cooperative work practices to reveal the situated nature of work [184][185]. As highlighted by Schmidt, cooperative work is inherently complex and characterised by interdependencies, necessitating sophisticated coordinative practices that are typically found in ordinary work settings [186].

The goal of CSCW research is to contribute to the development of effective technological solutions that foster cooperative and collaborative work practices and improve productivity in diverse social and organisational contexts. In addition, the focus of CSCW should be oriented towards the design of systems that incorporate an increasingly profound comprehension of the nature of cooperative work forms and practices [137]. The proclaimed aim of CSCW is to *"support via computers a specific category of work – cooperative work*", according to Schmidt and Bannon. The term "computer support" renders a dedication to prioritising the genuine needs and requirements of individuals engaged in cooperative work and it is acknowledged that technologies of communication and interaction will inevitably transform the way people collaborate. Thus, CSCW systems are expected to have a significant impact on existing cooperative work practices. However, it is important to recognise that cooperative work can be understood as a distinct category or aspect of human work, characterised by certain fundamental characteristics that remain consistent regardless of the availability of current or future technical facilities [137].

The term “cooperative work” is subject for confusion as there is a lack of clear definitions and distinctions between various forms of cooperation, in CSCW. In general, it is a neutral term used to refer to the collaborative efforts of multiple individuals working together to create a product or service, but as the word "cooperation" can carry various connotations in everyday language depending on the context in which it is used, Schmidt and Bannon arguments that the forms of cooperative work (including collaborative work, collective work, and group work, and the distinctions between them) are unclear. To support their argument, they draw on four examples: The first one is Hughes, Randall, and Shapiro who argue that all work is inherently socially organised, but a more specific definition of cooperative work could aid in understanding different forms of work activity [187]. On the other hand, Sørgaard has proposed specific criteria for cooperative work, such as non-hierarchical and autonomous characteristics [188]. A third perspective drawn upon by Schmidt and Bannon suggests that the term 'cooperative work' is inappropriate due to the ideology associated with it [137]. Thus, assuming compliance and shared sentiments, may not align with the realities of everyday work situations [Howard 1987]. Howard prefers the term 'collective work,' which he sees as being induced through the use of computers in various ways. Similarly, Kling (1991) concurs with the criticism of the allegedly positive connotations of the terms 'cooperation' and 'collaboration,' and suggests using the term 'coordination' instead [189]. Historically, the term "cooperative work" has a long history in the social sciences and has been used by economists since the first half of the 19th century to refer to work involving multiple actors. Marx defined cooperative work as "multiple individuals working together in a conscious way in the same production process or in different but connected production processes." [137]. The term has also been extensively used with the same general meaning in the German tradition of the sociology of work. At the core of the conception of cooperative work is the notion of interdependence in work. Work inherently has a social dimension, as it involves the interaction and mediation of various elements such as the object and subject, ends and means, motives and needs, implements and competencies. When people engage in cooperative work, they depend on each other’s work, which requires them to work together [137]. The mutual dependence in work can be exemplified through a situation where two parties, a mobile robot, and a human worker in a hospital, rely on each other's work: if the robot is to success in performing its task of transporting items around the hospital, the human worker must make sure that the robot is equipped with the items, before it drives off.
Because of the interdependency, it is vital to engage in secondary activities. Schmidt and Bannon state the following:

> *“Tasks have to be allocated to different members of the cooperative work arrangement: which worker is to do what, where, when? And in assigning a task to a worker, that*

worker is then rendered accountable for accomplishing that task according to certain criteria: when, where, how, how soon, what level of quality, etc.?" [137 p.51]

In addition, the cooperating parties will have to articulate their activities, which requires coordination and synchronisation of individual activities [190–192]. Hence, cooperative work is complicated in comparison to individual work, thus the justification for incurring these overhead costs and the emergence of cooperative work arrangements is the recognition that tasks cannot be efficiently accomplished in isolation [137]. Cooperative work relationships are considered to arise in response to technical or economic demands in specific work settings – while the dynamics of interaction in cooperative work evolve in response to the situational requirements and constraints. Cooperative work is spread out - both physically, across time and space, and logically, with agents having semi-autonomous control over their respective tasks. Additionally, cooperative work involves diverse perspectives, professions, specialties, work functions, responsibilities, as well as differing strategies and motives, which may not always align seamlessly. Further, cooperative work is characterised by the work activities that are interconnected in terms of content, as they contribute to the production of a specific product or service. Consequently, the boundaries of cooperative work networks are determined by actual collaborative behaviour and may not necessarily align with the formal boundaries of organisations.

While CSCW investigates human collaboration facilitated by technology, HRI explores the collaboration between humans and robots to achieve shared objectives. Collaboration lies at the core of both CSCW and HRI, wherein the accomplishment of tasks and objectives is contingent upon effective teamwork – and by understanding the dynamics of collaboration in CSCW and HRI, it is possible to gain valuable insights into how effective collaborative systems should be designed – and into how harmonious human-robot teamwork can be fostered.

In CSCW, collaboration revolves around task-oriented teamwork, wherein individuals work together to achieve specific goals. The emphasis lies in harnessing technology to facilitate human collaboration, enabling seamless communication, information sharing, and coordination. Collaborative technologies such as shared workspaces, video conferencing, and document sharing platforms play a pivotal role in enhancing team productivity. Further, effective communication and coordination are vital for successful collaboration in CSCW as clear and efficient information exchange enables team members to understand each other's intentions, actions, and progress. Communication channels and tools, both synchronous and asynchronous, foster collaboration by enabling real-time interactions and capturing a shared understanding of the task at hand. In addition, CSCW involves defining human roles, determining their tasks, and managing their interactions within the collaborative setting. In CSCW, understanding the distribution of roles and responsibilities is essential for effective collaboration and specialised roles, task allocation, and team coordination strategies contribute to achieving shared objectives.

In HRC, the collaboration between humans and robots is explored, aiming to design systems where robots seamlessly integrate into teams with humans, to accomplish tasks. This collaboration is characterised by human-robot interaction, where robots are assigned specific roles and tasks within the team structure. The success of HRI relies on establishing effective communication and coordination mechanisms between humans and robots. In HRI, understanding the roles and responsibilities of both humans and robots is crucial. Humans bring domain expertise, intuition, and contextual understanding, while robots contribute with their specialised capabilities, precision, and efficiency. Assigning appropriate roles to humans and robots and managing their interdependencies are critical factors for collaborative success in HRI. The collaboration in HRI is mediated by robotic systems, as robots act as team members and participate in the workflow, performing tasks alongside humans. The technical elements play a vital role in enabling communication and coordination between humans and robots, as advances in robot perception, cognition, and natural language processing enhance the robot's ability to understand and respond to human intentions, which ought to make the collaboration more seamless. Analysing HRI from a CSCW perspective can provide insights into how robots can be integrated into collaborative work environments and how technology can be designed to support effective human-robot collaboration.

3.9 Articulation work

Articulation Work is utilised as another analytical lens in this PhD study. This framework, developed by Anselm Strauss and colleagues, focuses on the coordination and communication challenges inherent in complex collaborative settings, and the framework is utilised with the aim of gaining valuable insights into exactly this, ensuring collaboration between hospital service staff and mobile robots. The Articulation Work framework allows for identification and analysis of specific work practices, processes, and interactions that hospital staff undertake to integrate robots into their routines and reveals the challenges and adjustments they face. Thus, providing a comprehensive understanding of the impact on work dynamics. Moreover, utilising the Articulation Work framework enhances workflow design and implementation. It helps identify bottlenecks, gaps, and areas of friction in the collaborative process, facilitating the development of strategies to optimise workflow efficiency and ensure effective integration of robots into healthcare settings.

As cooperative work arrangements are formed based on the interdependence of work activities, it is important to manage the distributed nature of these arrangements, coordinating and organising these. This process is known as articulation work: an essential component of cooperative work, involving the set of activities required to effectively manage and coordinate the distributed nature of collaborative work. The concept was originally formulated by Anselm Strauss [190,192,193] sociologist, who claimed articulation to be part of every social process or action [194]. Strauss's approach focuses on the "micromechanics" of social situations and has been successful in revealing the subtle processes by which the interactive customer service work process is influenced by the social environment [195]. This makes it a valuable tool for identifying otherwise "invisible" aspects of work, such as technology implementation and the unspoken management of the delicate social dynamics that emerge during customer service interactions, as noted by Korczynski [196]. Articulation work serves to bring attention to phenomena that are frequently overlooked, and it often involves routine and visible "management work".

This, while playing a crucial role in navigating the interactions between different "social worlds" and in the unspoken management of the delicate social dynamics that emerge in customer service interactions, as demonstrated by Korczynski. Articulation work can be of high complexity in work settings. To meet this complexity and the distribution of work both physically and logically, humans make use of different activities and tools for interaction, for example by using plans, schedules, standard operation procedures etc. These tools can help mitigate the complexity associated with articulating cooperative work. According to Gerson and Star, *"Articulation consists of all the tasks involved in assembling, scheduling, monitoring, and coordinating all of the steps necessary to complete a production task."* [191].

Articulation work encompasses the process of working out and implementing work-related arrangements, which involve coordinating and integrating various tasks, clusters of tasks, and segments of the overall work process. It also involves aligning the efforts of different workers and units within the organisation, as well as aligning actors with their respective work and tasks [190]. This process includes following through, following up, and working out details, with interactional processes playing a crucial role. These processes may include negotiation, compromise, lobbying, coercion, threat, and education, through which arrangements are established, maintained, and revised [193]. When articulating work in cooperative work, workers align their approaches to work, why it is crucial for them to reach a somewhat common state of meaning about and around the situation/process/phenomena [193]. Articulation work serves as a facilitator for this, not least by drawing on various social worlds encompassing actors' meanings (such as beliefs, attitudes, perspectives, and emotions), tasks, responsibilities, obligations, commitments, conceptual structures, diverse temporalities (i.e., different notions of time), and spatial considerations [197].

In relation to articulation work is Brown and DuGuid, who - in their account of organisational learning - emphasise the disparity between what they term as "canonical" accounts of work, which are rationalist in nature, and the actual intricacies involved in repairing photocopiers. Formal descriptions often "omit the details," and a comprehensive understanding of the work process requires meticulous observation and detailed accounts that capture the differences between the completed work process and its execution in real-time. Even those who perform the tasks may not fully grasp the tacit skills involved, and retrospective descriptions of work may be reconstructed in rationalistic terms, further obscuring the complexity of the actual work process. Such oversimplified accounts are often assumed by organisations, resulting in work being mapped onto simplistic steps without necessitating significant understanding nor insight [198]. However, these accounts not only fail to capture the true complexity of work as it is performed but may also hinder the actual process of performing the work. If there is a lack of articulation, the cooperative work might be insufficient. The notion of articulation work is vital, not least as the nature of work changes, for example because of robots being deployed in organisations. CSCW research conveys that institutions and organisations must be ready to meet these changes, which for example can be realised through coordinating activities across functions, by articulating work. While articulation work traditionally emphasises communicative processes, its application to HRC extends beyond verbal and nonverbal communication strategies to encompass the collaborative efforts and coordination mechanisms involved in facilitating interaction and collaboration between humans and robots. It involves the negotiation of meaning, understanding, roles, responsibilities, and actions between humans and robots to accomplish shared goals. It is crucial to delve into the negotiation of roles, responsibilities, and actions, as well as the establishment of mutual understanding and effective collaboration.

3.10 Plans and situated actions (Suchman)

Suchman's framework on Plans and Situated Action can provide a comprehensive understanding of the complex dynamics of human-robot interaction in hospitals. By utilising this framework, I aim to demonstrate a commitment to exploring the multifaceted aspects of technology integration, going beyond surface-level analysis to delve into nuanced interactions, adaptations, and workarounds that emerge in practice. Suchman's work has an established theoretical foundation in the field of human-computer interaction and technology studies, and as hospitals are unique sociotechnical environments, understanding the contextual factors at play is crucial. Suchman's framework recognises the significance of context and situational factors in shaping human behavior and technology use and employing her approach will emphasise the importance of context-specific analysis, capturing the intricacies and contingencies of human-robot interaction and collaboration in hospitals. Further, Suchman's perspective focuses on the practical aspects of technology use and the situated nature of human activities, underscoring the practical relevance of robot integration in hospitals, highlighting the tangible implications for hospital service staff and their work processes.

In "Plans and Situated Action", Suchman investigates how humans program software, particularly for robots. For instance, humans may instruct a robot to move left, then right, and then left again while navigating through a mase. If humans provide the robot with precise directions about the layout of the mase, the robot will be able to reach the other end of the mase without error [185]. However, the issue arises when the real world and life are not as simple as a mase. According to Suchman, our approach to problem-solving is interconnected with the immediate circumstances in which we find ourselves. Our actions in these moments are based on what is feasible and helpful to accomplish our objectives. What is critical to note here is that the context is never constant. Each time we interact with the context, it is akin to dipping our toes into a flowing river, and every time we do so, we touch a different river [185].Essentially, Suchman asserts that we can never list our plans or software with enough detail to account for changes in context. Suchman asserts that when designing new technologies, we should consider the broader environment and system rather than solely focusing on the technology itself:

"The efficiency of plans as representations comes precisely from the fact that they do not represent those practices and circumstances in all of their concrete detail. So, for example, in planning to run a series of rapids in a canoe, one is very likely to sit for a while above the falls and plan one's descent. The plan might go something like "I'll get as far over to the left as possible, try to make it between those two large rocks, then backferry hard to the right to make it

around that next bunch. A great deal of deliberation, discussion, simulation, and reconstruction may go into such a plan. But however detailed, the plan stops short of the actual business of getting your canoe through the falls. When it really comes down to the details of responding to currents and handling a canoe, you effectively abandon the plan and fall back on whatever embodied skills are available to you… the purpose of the plan in this case is not to get your canoe through the rapids, but rather to orient you in such a way that you can obtain the best possible position from which to use those embodied skills on which, in the final analysis, your success depends." [185].

Plans represent ideals and best-case scenarios; however they do not account for the context. Rather, plans serve as a guide, and the actions we take in response to the context around us are not always aligned with our plans. Consequently, technology solely based on plans without consideration for contextual differences will inevitably result in failure. Suchman's research delves into a crucial challenge regarding technological innovation. In her work exploring a corporation's way of handling challenges, she discovered how the corporation's ability to stay ahead of its competitors was by constantly developing more complex and versatile machines. However, this led to customers finding the machines increasingly difficult to comprehend and operate. This was a precarious situation for the corporation, as their competitive advantage rested on offering machines with more functions than their rivals. Nevertheless, if customers could only use a handful of functions, and those were the same as their competitor's machines, it undermined the corporation's market position. Initially, the corporation responded by providing more comprehensive instructions, but this strategy often proved overwhelming for users. There is a story of a proposal for a second set of instructions to clarify the first, creating the amusing image of a photocopier carrying sets of instructions, each one attempting to clarify the previous one, leading to an infinite series of instructions. In order to overcome the challenges they were facing, the corporation tried to use computers to make "intelligent machines" with "expert help systems", allowing for humans and machines to communicate. In essence, the concept behind the expert system was to enable the machine to comprehend the user and provide guidance towards the desired outcome, should the user be unable to comprehend the machine. By breaking down human problems into a specific objective, the machine could formulate and carry out a suitable plan to attain that goal [185].

At the time for Suchman's research, it was widely believed that goals, plans and problem-solving could accurately describe behaviour of both humans and machines. However, as Suchman observed multiple human-machine interactions, she revealed that these rarely went as planned, whether it was the human's or the machine's plan. In a well-known video study called "When User Hits Machine", Suchman depicted two men attempting to follow a photocopying plan but were hindered by the machine's instructions and behaviour. Instead of producing a neat set of photocopies, they ended up creating what could be perceived as a comical act. According to Suchman's argument, the conflict between users and machines arose due to a discrepancy between the designers' conception of how plans should ideally be formulated and executed and how they are actually carried out in reality. She demonstrated that the "communication" between a user and a machine was not a dialogue between two equivalent intelligences, as designers had presumed. Ethnomethodologists have demonstrated that ordinary conversation is incredibly intricate, utilising efficient linguistic indexicals, suggestive nonverbal cues, turn-taking customs, contextual resources, and open-ended discourse. Conversely, the concepts of "interaction" and "intelligence" integrated into machines were notably limited, lacking the complexity of human conversation. The ethnomethodological approach centres around the concept of sense-making. Humans attempt to comprehend their surroundings, establish goals, and utilise various contextual constraints to improvise and create communicative resources. This kind of improvisation is not feasible for a machine designed to adhere to predetermined plans and presuppose that humans will do the same. However, Suchman did not propose situated action as a substitute for planning. Instead, she illustrated how plans were "discursive tools" that necessitated interpretation via situated action. Thus, plans could not be presented as an external, preconceived method for managing action, but only as one of many resources. Suchman aimed to comprehend plans rather than reject them and elucidate to those who heavily relied on the notion how plans were practically executed. In doing so, she differentiated between machines designed to execute predetermined plans with precision and humans who employ plans contextually and improvisationally, considering them only one of numerous action guides. Her work made a noteworthy contribution to the then emerging fields of Science and Technology Studies and Computer-Supported Cooperative Work. The shift of focus from "human-machine communications" to "computer-supported" work, and from the individualised "expert system" to the social system embodied by the concept of "cooperative" accurately reflects Suchman's impact trajectory [185].

Contemplating HRI by the lens of plans and situated actions involves examining how robots and humans interact in real-world situations and how they use plans to accomplish their tasks. This perspective encompasses that actions are situated in a context and are shaped by the environment in which they occur. By analysing HRI from the perspective of plans and situated actions, the interactions between humans and hospital staff and how they adapt to changing situations can be characterised. This perspective can also help identify challenges and opportunities for designing robots that can work effectively in collaborative environments.

3.11 Understanding organisational change through the Leavitt Diamond model

The kernel of implementing new technology in organisations lies in the considering that organisational leaders often fail to recognise that such entails substantial changes. Therefore, a prerequisite for success is for the organisation to develop a model within this area to anticipate any potential problems in a constructive way. A range of such exists, for example Lorenzi and Riley's model [199], The Process Model [200] and Leavitt's Diamond Model [201]. The last-mentioned is one of the most well-known and used models of organisational change. It is included in this work, as it is useful in explaining the interplay between different organisational elements and can be used as outset for a discussion of how robots influence hospital organisations.

The Leavitt Diamond model is a comprehensive model utilised for managing organisational change. It is widely used to explain the interplay between the elements in organisations, particularly between the four components: tasks, people, structure and technology [201]. The model was created by Dr. Harold Leavitt in 1965 and grounded in organisational theory. It emphasises the importance of evaluating the potential impact of changes made to any of its four components on the other three components before implementing any changes. In order to achieve successful change, it is necessary to strike a balance among all four components in the model. The four components are characterised in the following:

1. Tasks
    a. The task component refers to the actions that need to be taken to deliver value: work tasks. These tasks are carried out by individuals and teams within a department. During organisational change, it is crucial to comprehend the current tasks and compare them with the future tasks. By doing so, it becomes easier to develop communication and training programs to fill the gap. In cases of organisational restructuring, where roles are being made redundant or shifted to other departments, it is essential to identify all the tasks, who will perform them, and how they will be carried out in the new environment.
2. People
    a. The people component represents the workforce and their skills, values, motivation, attitudes, and behaviours. Their individual context influences their ability to perform tasks effectively – and the relations between the people can be dependent of the tasks they are performing. To facilitate successful organisational change, it is essential to assess and understand the required skills, behaviours, and attitudes that employees need to possess in the new environment.
3. Structure
    a. The structural component pertains to how people and teams are organised in the organisation, for example hierarchy or allocation of tasks between departments. It encompasses not just the hierarchical arrangement but also the relationships, communication patterns, and coordination between different management levels, departments, and employees. This also encompasses how authority and responsibility are delegated within the organisation. When changes are made to any other component of the diamond, the structure may need to be modified accordingly.
4. Technology
    a. The technological component concerns the tools, equipment, and machinery utilised by individuals to carry out their tasks. Technology can also refer to processes and procedures related to the technology.

In short, the Task variable covers all the tasks and subtasks that contribute to providing products and services, the People variable refers to the individuals who perform the tasks associated with organisational objectives, the Structure variable pertains to the communication systems, authority systems, and workflow within the organisation – and the Technological variable encompasses all the machinery and equipment necessary for the task variable. The model is illustrated in the figure below.

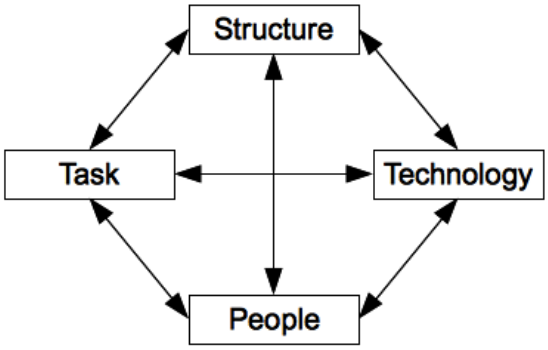


Figure 17 Leavitt Diamond Model

Picture from https://lapaas.com/leavitts-diamond-an-integrated-approach-to-change/

The diamond-shaped arrows in the model illustrate the interdependence of the four variables. Leavitt contends that any change in one of the variables will have an impact on the other variables. When a planned change in, to give an example, the technology component is made, - this could be the implementation of robots in hospitals – it can impact one or more of the other variables. The implementation of robots can impact the structure, the people and the tasks. The use of new technology necessitates people to undergo training, which could impact the organisational structure by increasing demands for better pay and positions. Moreover, new technology may change old tasks since it may automate previous processes, requiring people to perform work differently – or perform different work [201]. Consequently, it is crucial to assess the influence of the change, on all four components before initiating any change. Finding a proper balance among these components is essential to implementing changes successfully. Typically, interventions are aimed at bringing positive changes to the task variable, which involves enhancing the quality of products or services. In the aforementioned example, the other variables are also likely to be influenced, such as the increase in morale (i.e., people) and improvement in communication (i.e. structure) due to the new technology. Although the Leavitt's Diamond model portrays the variables as interdependent and dynamic, it is not complex enough to make direct causal statements regarding the four variables. However, the Diamond acknowledges that technology is closely linked to the necessary tasks, individuals, and structural organisation, which is why this model has been extensively utilised as a foundation for comprehending and implementing changes within organisations. his model proposes that a balanced consideration of all four variables is essential for comprehending knowledge management operations within an organisation. Instead of dismissing the importance of any variable or completely disregarding a constituent (such as technology), this framework regards all groups and elements equally and prioritises all variables.

4 FINDINGS

"One might ask me; how can you actually trust that the robots do what they are supposed to? Then, I'll answer that I can't do anything but set them up, take a chance.. And hope it works."

Hospital Technician

In this chapter, the findings of present PhD project are outlined. These stem from the field studies, Study I, Study II and Study III, at three different hospital sites, and from the scoping review. The three different hospital sites are respectively the Hospital of Southern Jutland in Sønderborg (SHS Sønderborg), the Hospital of Southern Jutland in Aabenraa (SHS Aabenraa) and Odense University Hospital (OUH). The term SHS is occasionally used interchangeably but when it is vital to distinguish between SHS Sønderborg and SHS Aabenraa, the names are specified.

Findings published in peer-reviewed research papers are presented in this chapter. However, the publications are, due to sharp focus, limited scope and stringency, limited and certain insights are left out, for forms sake. However, these certain insights than the ones published, shed light on HRC and are important to convey, as they act as clear rays of light, revealing through tiny cracks between the big timbers. Thus, they are communicated in this chapter, in the sections outlining the published findings. The chapter thereby holds findings described in publications and findings that has not yet been revealed. The reader will be able to distinguish published and unpublished findings from each other, as the published findings are marked with references for the papers, while the unpublished are referred to with the following: [unpublished].

The chapter presents the findings in a sequential manner, with the order of studies determined by their place in the research process, whereby studies are presented based on when they were initiated. The findings communicated in Paper I and Paper II stems from the field study at SHS Sønderborg, while the findings in Paper III derives from the field study at OUH. The findings from Paper IV are from the scoping review. The findings from Aabenraa are unpublished and therefore referred to as *[unpublished]*.

The first study outlined is from the Hospital of Southern Jutland in Sønderborg, communicated in Paper I (*Investigating human-robot cooperation in a hospital environment*: *Scrutinising visions and actual realisation of mobile robots in service work*") and Paper II (How socio-technical factors can undermine expectations of human-robot cooperation in hospitals"). These convey empirical insights and understanding of the concept *human-robot collaboration* between hospital kitchen staff and mobile robots and illustrate the role of socio-technical factors, including the unstructured real-world setting, in human-robot collaboration.
After the findings from Sønderborg are outlined, insights gained from the Hospital of Southern Jutland in Aabenraa, Study II, are communicated. This is followed by a section outlining the

findings from Odense University Hospital, Study III. The findings from Odense have, by the time of finishing this PhD thesis, just been accepted for publication in conference proceedings of the RO-MAN conference in South Korea. The paper is titled “Understanding human-robot teamwork in the wild: The difference between success and failure for mobile robots in hospitals”. The findings from the field studies addresses research question 1 and 2.
The empirical findings are followed by findings from the review titled “A scoping review and conceptual framework for understanding human-robot collaboration at work in hospitals”, addressing research question 3, *What are key elements in a conceptual framework for HRC at work in hospitals?*

4.1 OUTLINING THE FINDINGS

In the following, the findings addressing the research questions are presented.

4.1.1 Findings from Study I (SHS Sønderborg), published in Paper I

In the first study, communicated in the paper *Investigating human-robot cooperation in a hospital environment: Scrutinizing visions and actual realization of mobile robots in service work* [1], the aim was to explore how human-robot collaboration unfolded in a hospital setting, in a medium-sized hospital in Sønderborg, Denmark. In 2016, two mobile robots were deployed to aid kitchen staff with transporting carts in the narrow hospital basement, which held heavy traffic from a diverse group of individuals, including patients, clinicians, laboratory technicians, kitchen staff, porters, technical staff, and workmen, deemed a crowded, busy setting [1].

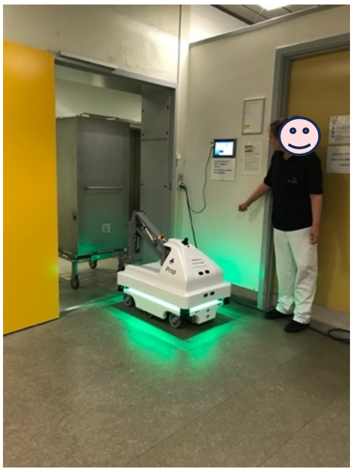


Figure 18 Hospital service staff member making room for the mobile robot to enter the room

The utilised method was ethnographic inspired field study, carried out in May 2020, holding a mixed-method approach comprising interviews with kitchen and porter staff, kitchen management and healthcare professionals; observational studies of robots in action; and guided tours where informants explained their actions while performing tasks and cooperated/not cooperated with the robots. In addition, I shadowed the two robots, named Prop and Berta, throughout the

days, from early morning when they started their workday, to late afternoon where their shifts ended. I followed them around, always having an eye on them, witnessing their actions, and watching their behaviour, as they worked, failed and everything in between. The insights gained in the field were taken home as thick, descriptive field notes, photos, videos, and audio files with recorded interviews, with 26 informants, equivalent to 9,97 hours of audio. The kitchen staff were included in the study due to their extensive cooperation with the robots, the healthcare professional was included after interfering with one of the robots, and the porters were included because of their regular interactions with the robots throughout the day. The participants were observed along with other humans in the basement, including patients, clinicians, laboratory technicians, technical staff, and workmen.
The study uncovered various situations that demonstrated the intricate nature of incorporating robots into unstructured work environments, along with the challenges that arise when the deployment of robots resulted in insufficient automation of tasks and processes. These are outlined in the following sections [1].

4.1.1.1 The robots

The type of mobile service robot in use at Sønderborg Hospital was widely used in industry, where it operated without much interaction with humans, but had gradually gained acceptance in hospitals to optimise logistics and had to interact with humans in a dynamic hospital environment. In an interview, the hospital kitchen manager explained that the robots were deployed in 2016 to ease the work of the kitchen service staff, in the wake of the implementation of a new food concept for patients. The hospital intended to provide the patients with a higher quality food experience while being at the hospital and deployed the robots to support staff in their daily working routines and relieve them in physical tasks, such as transporting carts with cutlery, glass, and dishes around the hospital. In an interview, the kitchen deputy manager specified this vision and shared how it had been realised by the robots identifying service carts to pick up around the hospital by the use of QR codes. During the field study, it was observed how the robot would pick up a cart by using its hook, attach the cart to itself and drive around the cellar with the cart, placing it in another predefined spot, from where the hospital kitchen service staff could pick it up and push it inside an elevator and navigate it further to a hospital ward, where the cart would be used. The robots had integrated sensors to ensure they moved around the hallways in a safe manner, without driving into humans and obstacles. The sensors were the only input making the robots capable of noticing the setting they were situated in, and the objects therein, and they only stopped when they identified humans and obstacles too close to them or when a human forced them to stop, by pushing the 'STOP'-button, which was only to be used in case of emergency. Further, the robots were equipped with joysticks on their front cases, which was a requirement from the hospital management, enabling different hospital staff groups to manually move the robots around, in urgent cases, such as if the robots drove out in front of staff handling emergencies. In addition to this, it was possible to set the robots in manual mode and control them through a specific tablet [1].

The robots mainly ran tasks that were coded in a fleet management system and performed tasks or missions that the kitchen service staff could define through the aforementioned specific tablet, which was located in a room colloquially called ‘The Robot Garage’ in the basement.

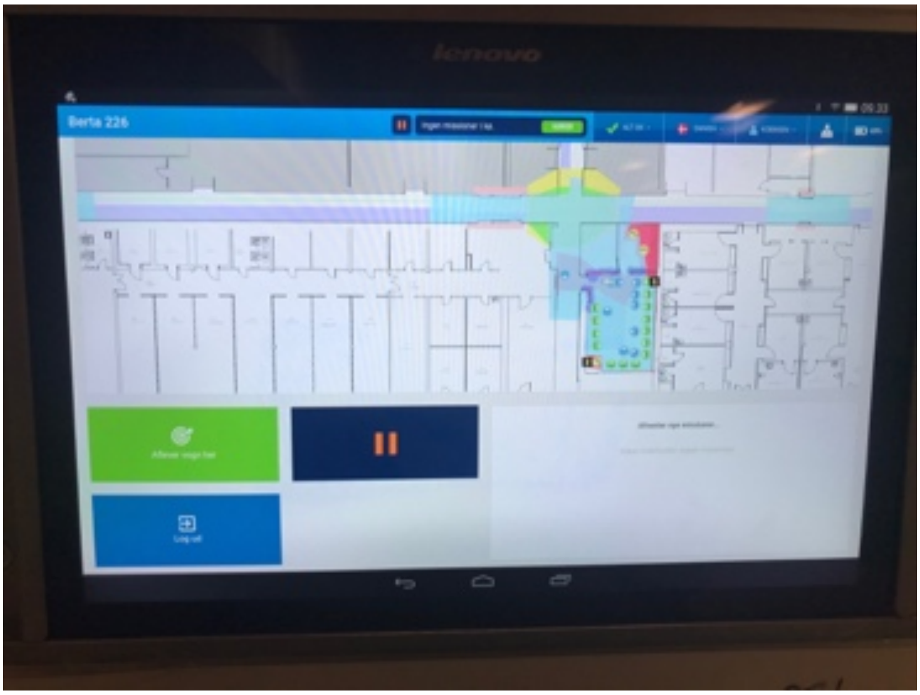


Figure 19 Overview of the hospital basement on the tablet in the Robot Garage

On the tablet, kitchen service staff were able to access a map and get an overview of the robots' whereabouts, as well as send them off on missions through a web-based user interface. During the robots' operations, the staff were able to monitor their navigation via the map on the tablet. By using this map, the staff could detect whether the robots were fulfilling their missions or had stopped somewhere on the route. However, the staff could only monitor the robots' whereabouts within a certain geographical range. If the robots went beyond this range, the staff would lose connection and track of the robots and would have to physically search for them through the hospital hallways. When the robots were not running missions, they would park in The Robot Garage, where their docking chargers and associated robot manuals were located [unpublished].

Figure 20 The mobile robots Prop and Berta in the Robot Garage

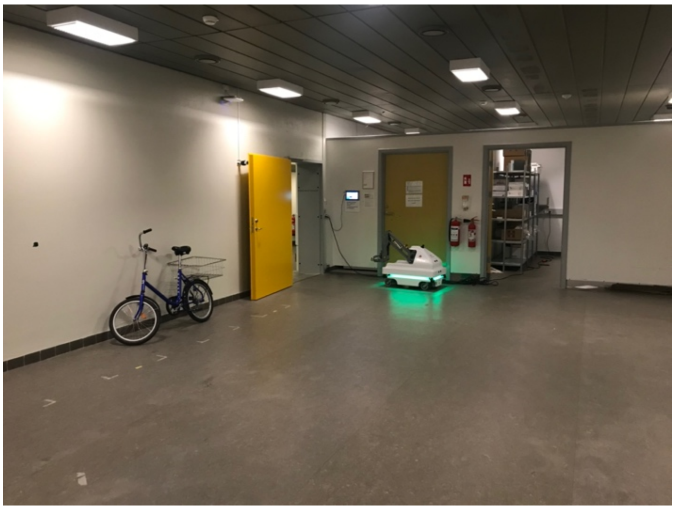


Figure 21 One of the mobile robots in the Robot Garage

4.1.1.2 Names and personalisation

In the interview with the hospital kitchen manager, she explained how she and the rest of the management had decided to give the robots names to ease the acceptance of the robots among different groups of hospital staff. They named the robots Prop and Berta, which resembled a popular Danish children's book and movie about a man, Prop, and his best friend, a cow, Berta. The aim of giving the robots names was to make it easier for the service staff to become familiar with the robots. One of the kitchen staff members stated that it was more affecting for her and her colleagues to be part of an interaction with something that held a name, rather than a number. The names Prop and Berta made the kitchen staff talk about the robots as if they were persons/personifications and as if the robots held gender. For example, it was common for the kitchen staff to refer to Prop as male and Berta as female. According to the leader of the kitchen, the aim of naming the robots was to make the kitchen staff more comfortable and familiar with the technology and try to foster trust in the two robots [unpublished]. The kitchen manager stated the following:

"[…] one of the reasons why we have given them names is that our employees should find it a bit fun and cosy. They [the employees] voted on two names during our New Year's reception. And it also creates some trust in the robots, that they are not just called 1 and 2. It helps to personalise it a bit more. And when we call [the robot support] today, we say, 'We just need to look at Berta, because she is standing...' and then they ask 'Excuse me, but did you say 'she'?'. But we do! Because it's a boy and a girl. But some of our porters really think it's rubbish. They think it's too bad when our meal hosts need to use their elevator, they speak rudely to and about us and the robots, something like "You damn well just...". And then I usually say, 'Listen, we speak nicely to you, would you also speak nicely to Berta? She can actually get upset.' So it's to give the robot something that makes people milder towards it, than if it was called 1 or 2." [unpublished].

She elaborated on the personalisation of the robots and talked about a younger employee who went further than names in personalising the robots, he was making up stories about them, which made HRC more fun and exciting:

"We had a substitute here who was on a gap year, he was an on-call substitute. He got the robots on his phone because... well, he thought it was really fun. He was crazy about those robots. He would say things like 'Oh! The twins are acting up again' and 'And then Berta went up to Ejner[2], I think she's fallen in love with him', instead of driving down to his own charger, and such things - he really got into it, and it was just so fun to see. Prop, Berta and Ejner, they use the same fleet management, so there were some errors allowing for Berta to run wild - but we have only experienced it that one time. Ejner charges behind the sterilisation center and our substitute just said that 'Now she's fallen in love with Ejner'. And that talk about the robots, as if they were almost like a trio, it was just so nice and cosy. It makes this really fun!" [unpublished]

When asked if she thought the kitchen staff perceived the robots as colleagues, she stated:

"*No. More like a tool they can send out. But they refer to them as Prop and Berta. It's not like they think 'this is my colleague and I have to be nice to it', but it's Prop and Berta. Not just 'those damn robots 1 and 2'."* [unpublished]

4.1.1.3 Robots at work

Prop and Berta could only run in the cellar, because they were unable to fit into the hospital elevators when the carts were attached. As a consequence, the robots did not transport carts to e.g. the surgery wards, but only moved carts for the kitchen service staff. The hospital kitchen manager explained in an interview that the decision to focus the robot tasks on kitchen services was also a result of the robots not being reliable enough for the hospital management to charge them with critical tasks such as transporting blood [1].

[2] Ejner was the name of another mobile robots installed at another ward of the hospital.

Figure 22 Mobile robot with cart attached, taking up space in the hallway at SHS Sønderborg

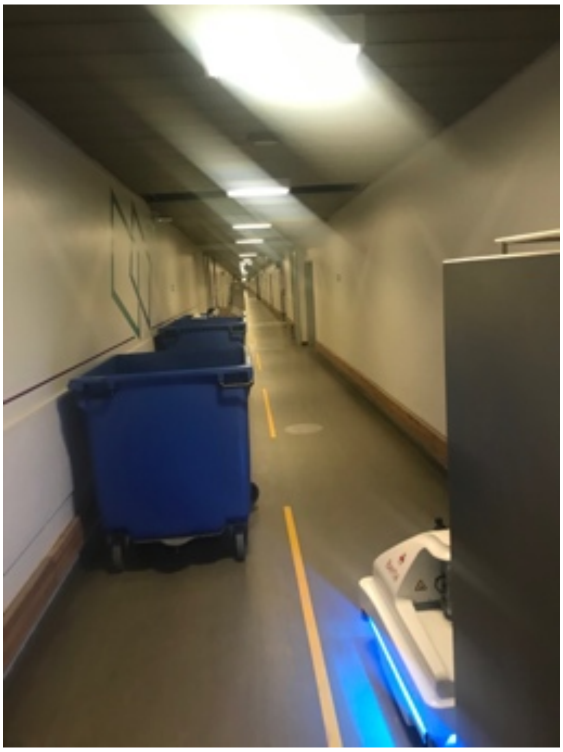


Figure 23 Mobile robot with cart attached, driving in the hallway at SHS Sønderborg

Figure 22 and 23 shows that the hallways of the hospital basement were narrow, and as a consequence, the robots were programmed to not drive next to each other. During the field study, it was observed how the robots had to navigate and drive around humans that were near, with a certain amount of space (for safety reasons), and took large turns, for mechanical reasons. A consequence of the narrow hallways combined with the large robot movements was that the robots took up a lot of space in the hallways when working.

According to the hospital kitchen managers in the study, the visions for deploying robots in the hospital kitchen logistics chain were to relieve staff from heavy pulling and pushing of carts; improve the working environment for kitchen staff; increase the experienced service for patients; optimise workflows and logistics; and increase efficiency by saving time spent on courier tasks. There were dreams, aspirations, and visions of automating certain parts of courier tasks with mobile robots, perceiving them as plug-and-play solutions to implement with ease [1].

4.1.1.4 Robots changing work

The study found that the robots changed the work done by the hospital kitchen staff, rather than reducing their workload. The general attitude that the hospital kitchen staff had towards the mobile service robots, Prop and Berta, was that the robots were rather tools than co-workers. The general perception of Prop and Berta among the kitchen staff was that the robots were a technology meant to be helpful towards the staff, but it was quite often the robots that needed help from the kitchen staff. As the kitchen staff experienced technical issues with the mobile service robots, they found it difficult to keep up their motivation for using the robots, rather than doing tasks themselves .

If a robot stopped somewhere, the kitchen staff had to go out and find it, when they realised that something was wrong. If the robot had some kind of breakdown, the staff were unable to send the robot back to the Robot Garage but had to use the joystick and guide/control the robot, all the way back to the garage. But if the joystick did not work, the kitchen staff had to use a smartphone to control the robot by logging into Prop or Berta's own Wi-Fi, from that point going to the developer's website and from there finding the map of the robot, the route of the robot, its mission list, and yet an interactive joystick, to control the robot with. But that was a difficult path to take, which made the staff call the developers, who might not be able to solve the issues right away. All of a sudden, the robots went from being sets of extra hands to being a nuisance, an obstacle that took time. And when that happened, the kitchen staff tended to themselves. One of them stated, in one of the short, on-site interviews, that:

"If I want something to be done, I will need to do it myself." [1].

As a result, the kitchen had functioned as caretakers for the robots and the robots had imposed additional duties on the staff, instead of assuming responsibilities as planned to improve work procedures and increase efficiency. In general, the kitchen staff had devoted a significant amount of time to assisting the robots in completing tasks, which did not align with the kitchen managers' perception that the robots would enhance work procedures. Rather, the staff had viewed the robots as complex, time-intensive sources of supplementary work and consequently, 50% of the kitchen staff had preferred to work without the robots. This illustrated how robots had mandated alterations to daily work routines, instead of reducing human workloads or substituting the human workforce, in the given hospital [1].

4.1.1.5 Complex work processes

The findings demonstrate why the envisioned implementation of robots in the hospital was challenging and how the realisation of cooperation between the kitchen staff and robots was complex. Neither the hospital nor kitchen managers fully comprehended the complexity of the tasks carried out by the kitchen staff and the robots due to the invisibility of many steps and informal procedures: while managers may have anticipated that the robots would perform tasks automatically, this study revealed the steps and procedures involved in these tasks, exposing the actual work practices and informal practices that supported the work of both the kitchen staff and robots. In order to accomplish the daily working routines of the hospital kitchen, tasks were divided and coordinated between the hospital kitchen staff members and the mobile service robots.

In an interview with the kitchen deputy manager, she explained how formal division of labour was assigned from the hospital kitchen management and placed between kitchen service staff and mobile service robots. She clarified how it was a simple task to perform, when a robot was ordered to move a service cart from point A to point B: the robot would drive to cart, grab it and move it from point A to point B, such as shown in Figure 24.

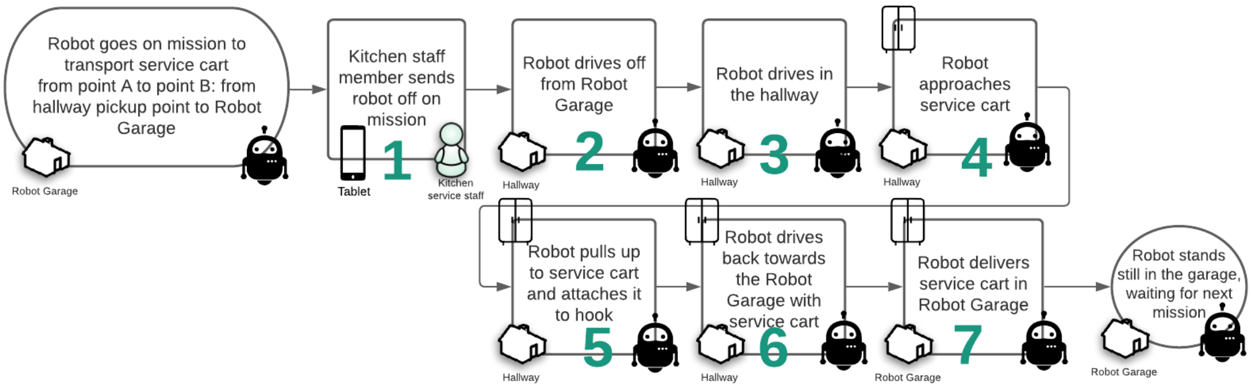


Figure 24 Verbally reported overview of workflow of mobile service robot going on mission to pick up and transport service cart, according to kitchen deputy manager [1]

Figure 24 illustrates the visible processes of the robots' work, as anticipated and elaborated by the deputy manager. In this workflow process, the robot is sent on mission and drive off to accomplish it, by moving down the hallway, approaching and attaching cart and then simply bringing the cart back to the Robot Garage. These processes were seemingly simple but through technology tours with kitchen service staff and robots, the performance was, and light was shed on how several steps and procedures in these tasks were unspecified, invisible and informal. It became clear that the robotic workflows were more complex than told by the kitchen management and kitchen service staff informants. Figure 6 holds a comprehensive overview of the complex process of a robot transporting a service cart from one point to another, which consisted of 28 different steps, in sharp contrast to the verbally reported 7 step workflow. Figure 24 will not be elaborated in detail, yet certain processes of impact will be highlighted [1]. When observing the steps the robot would have to go through when accomplishing the task of picking up and transporting a service cart, it became clear, when a robot was sent on a mission by a member of the kitchen service staff group, how the robot would drive off from the Robot Garage, into the hallway in an extremely slow pace, in order not to crash into the narrow door frame. Then, the robot would drive into the hallway and take part in an environment that held mixed traffic and therefore the robot would loudly express its presence by using alerting sounds and flashing lights (step 1-5). In step 6-11 it is shown how a member of the porter service staff group approached a robot, drove too close to it which made it stop and the porter became furious, since the robot would slow down his pace of work. In step 13 a healthcare professional pulled out in front of the robot and the consequences of this is shown in step 14-19. In step 14, the robot stopped as soon as its sensors registered movements and then started to play alerting, loud sounds ("Please step back! Please step back! Please step back!") and the lights started flashing, in order to warn the surroundings. It was observed how the healthcare professional started to swear and express her frustrations upon the robot, and as the robot was standing still, warning and recalibrating, a member of the kitchen service staff came pulling up towards the robot, with a cart full of warm meals for patients, she was on her way to deliver (step 17). Unfortunately, she was unable to get pass the robot, since it had stopped in the middle of the narrow hallway, blocking traffic. As a consequence, the kitchen service staff member and the healthcare professional would have to wait for the robot to recalibrate and drive on, before they could move on with their tasks.. After 5 minutes, the robot was ready to proceed (step 20), drove on and then attached the service cart to its hook, taking a giant turn which again blocked the narrow hallway, before driving on towards the Robot Garage, to unload the service cart. In step 23-25, another member of the porter service staff group pulled up, in a truck, behind the robot and had to drive behind it, which made him angry, since the robot was causing the porter to slow down the speed he was driving in. In step 26-28 the robot drove on and arrived at the Robot Garage, where it unloaded the service cart. When it had done that, the kitchen staff members were able to take the service cart further, to reach its final destination.

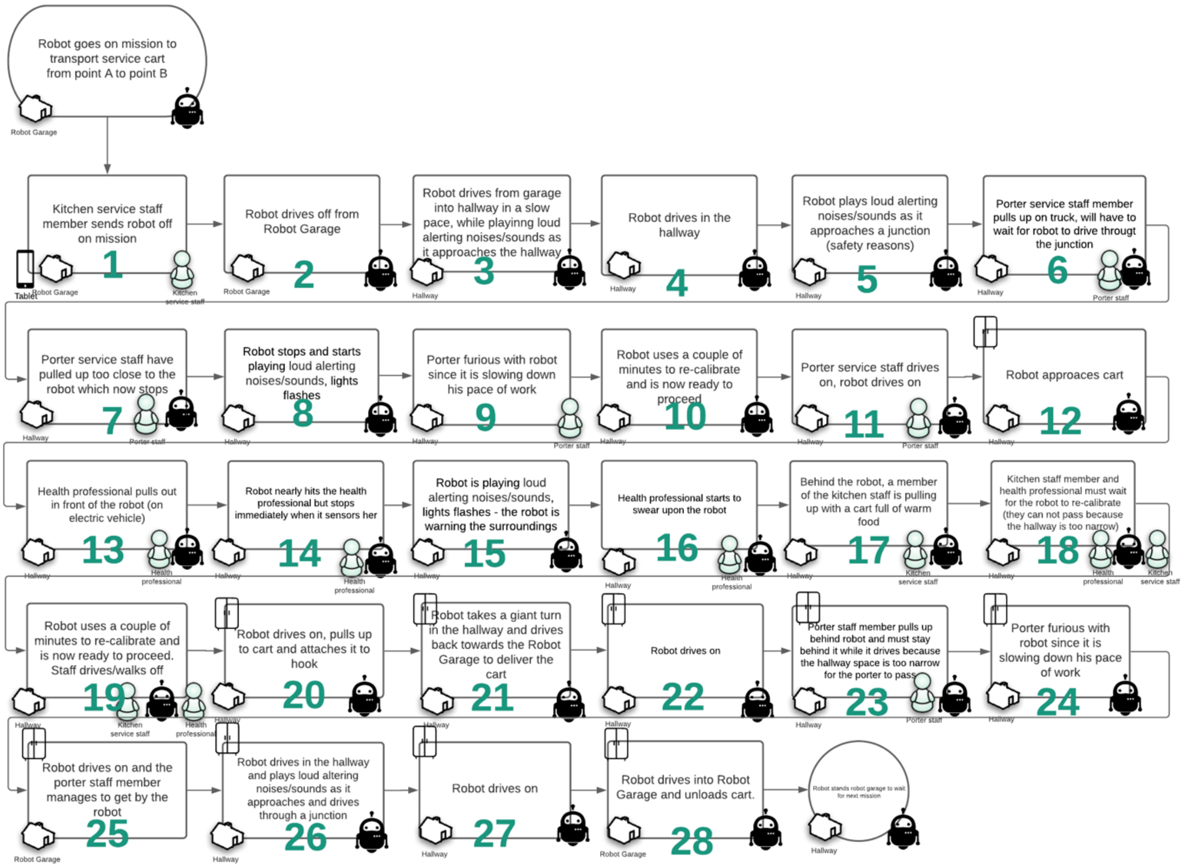


Figure 25 Overview of observed steps of accomplishing the task of picking up and transport service cart for mobile service robot [1]

These invisible and unnoticed procedures in tasks turned out to play a great role in the everyday cooperation between kitchen service staff and robots, yet the staff were not aware of the complexity of the processes. Through interviews, the kitchen service staff informants were asked to elaborate how the robots were completing tasks and 2 of the 16 members of the kitchen service staff group were aware of a number of the processes, the robots encountered during their missions.

The cooperation between humans and robots in the studied context was complex, as the expectations that robots would autonomously carry out simple tasks, while their collaboration with staff necessitated a comprehensive set of interactions, unbeknownst to managers. These interactions created interdependence between robots and staff, which added to the complexity. Consequently, it became clear that there was a mismatch between the visions of having deployed robots in the given hospital and the actual realisation of the collaboration between them and the staff, emphasising the complexity of deploying robots in new applications, such as hospitals [1].

4.1.1.6 Talking about robots

In the hospital, there seemed to be a certain way of talking about the robots, a mocking tone, from both kitchen staff and porters [unpublished]. This is exemplified below, firstly through the following scenario:

I am standing in the hallway as a woman from the kitchen staff group comes out of the elevator. In the same moment, one of her colleagues is about to enter the elevator and they do the "hall-way dance". One of them says, "Even though I'm not a robot, I can easily pretend to be one, standing here in your way!", while she laughs. Then they both laugh. [unpublished]

The mocking approach also came to surface when I followed the robots and was approached by porters, one of them asked:

“"You're simply taking it for a walk?!" [unpublished]

while he laughed.
Another porter tried to encourage me to optimise the robots, asking:

“Can't you control them and make them a little smarter and better than they can themselves?" [unpublished]

with a twinkle in his eye, but still in a serious matter. Another one said to me, as a robot was taking a large turn around a corner:

"Look at it, it takes the biggest damn TURN, leaving no space for us!! We have to move several meters so it can get around. It's so inefficient! I'm always waiting for that damn robot!" [unpublished]

Another similar episode took place with another porter, who passed me on a truck, asking if I was the one to control the robots, and I replied that I was just watching them. He responded:

"You're just going to watch them? Well, then tell them how stupidly they're behaving! They take huge detours around everything! It's completely unnecessary! The robot drives in the middle of the road, taking up all the space, so we can't be here. I have to slow down and drive behind it, and it moves slowly, damn it, it's annoying!" [unpublished]

In the study, a crucial factor for frustration was identified: the benefit factor. If you, as a member of a staff group, did not benefit from using the robot, you were most likely to be frustrated with them driving around the cellar, because they took up space, drove slowly and were loud in order to warn the surroundings that a robot was approaching [1].

The robots needed time to scan the surroundings and the phenomena it was part of within this environment where it was not situated, fixated, nor limited. If the robot, for example, sensed a human coming close to it, or it passed a container that was not usually in the hallway, the robot needed time to scan the surroundings – and when the robots were doing so, they lowered the tempo they were driving in for safety reasons, in order to not harm anyone or anything in its surroundings. During the day, a wide range of people (such as patients and different hospital staff members) found their way through the cellar and not many of them were aware why the robots acted the way they did. When they approached a robot that suddenly stopped and started warning with sounds and lights, people reacted differently, depending on what their errand in the hospital was. If it was the kitchen staff approaching the robot, they knew what to do in order for the robot to continue its routine – and they gave the robot time to calibrate and adapt to the situation. If it was patients approaching, they were most likely to get wondering and curious on this technology. If it was healthcare professionals, they walked right past the robots and continued what they were doing, almost as if they did not notice the robot standing there – and finally, the hospital porters were the ones most likely to get irritated with the robots when they slowed down or stopped in the hallways [unpublished].

A member of the kitchen staff group explained that the porters believed the robots were 'garbage' and the crux of it, she believed, was that the porters perceived the robots as a threat to their work and profession, as the porters used to transport the food trolleys that the robots were transporting: the responsibilities that were once the porters', now belongs to the kitchen, who have delegated the task to the robots. The robots had conquered porter territory. Consequently, some porters turned to sabotaging the robots [unpublished]. Another kitchen staff member stated:

"If you don't use the robots yourself, you don't have as many concerns about sabotaging them. 'I was here first, I have priority,' some people think. They forget that they are also hindering themselves."
[unpublished]

The statement, that people forgot that the sabotage also hindered their own efforts, covered the idea that when robots were hindered in successfully performing the tasks delegated to them, they might cause even more frustration. For example, if a porter sabotaged a robot by placing something in the hallway that the robot could not pass, it would stop in the middle of the hallway, trying to calculate another route while blocking passage, hindering the porters from crossing the robot, slowing down their work even further and fostering more irritation [unpublished].

The porters spent a great amount of time in the cellar, and especially some of the members from this staff group tended to perceive Prop and Berta as 'in their way', annoying, stupid, and unnecessary. A group of the porters verbally assaulted Prop and Berta. An example was one of the porters describing the robots as follows:

"*It is not just one, but two pains in my ass, because all these robots do, is to be in the way, being loud and being slow! I cannot get work done, because of these!"* [unpublished]

The porters’ narrative, stating that the robots were causing chaos and hindering their work, was further fuelled when the robots drove at a slow pace in the hallways, which did not harmonise with the porters' fast-paced work in large trucks. If the porters drove behind Prop or Berta, they had to slow down significantly and were not always able to overtake/pass by the robots due to the narrow hallways. An example of this occurred when Prop was driving in the hallway and suddenly turned from the lane it was into the middle of the hallway. It turned out that Berta was approaching from around a corner, so in order to not be in the way of Berta, Prop drove from the middle of the hallway to the opposite side of the hall. However, Prop had not yet registered that a porter on a large truck was coming down the hallway extremely quickly. The porter managed to stop just in time to avoid hitting Prop and reversed to make room for the robot to move along and finish the turn it was trying to take. But just before the porter started to reverse, Prop registered the porter, causing the robot to stop immediately (in order to not harm the human). Then, the robot alarm went off and constantly repeated "Please step back, please step back, please step back" while the lights underneath the robot flashed for five minutes before the robot stopped and moved on. The porter could not complete his tasks until Prop had moved, causing him to become frustrated, angry, and swear at the robot. Situations like this paved the way for the porters to put items in the spots where the robots go to drop off carts, making it impossible for the robots to complete their tasks throughout the day [unpublished].
Other staff groups, whose task performance was not affected by robotic presence, stated how they perceived the robots as funny and amusing:

> *"Oh well, those robots... They are something special. Look at them. [one robot is 'stuck' in the doorway without an obvious reason]. It doesn't bother me that they drive slowly. I just wait. And that's what I usually do. It has some strange paths - and habits. It's a bit funny."* [unpublished]

4.1.1.7 Non-use

Through the field study it became clear that the elder staff members wanted to use the robots to a greater extent than the younger ones and get relieved from the heavy pulling and pushing of carts [unpublished]. An example hereof is given through the following quote by a younger member of the kitchen staff group:

> *”Most people who have the morning shift are actually the elderly, and they use the robots a lot because the carts are heavy. Therefore, the robots are mostly used in the morning. But otherwise, at other times, I myself retrieve the carts, for example in the afternoon […] because it takes a long time to wait for the robots to pick up the carts so that the dirty [cutlery and dishes] can be put in the dishwasher and that needs to be emptied - and the carts need to be filled with the clean ones before they are ready again. Sometimes I cannot make it in time if I don't just retrieve the carts myself. I know some people use them all the time, but many of us young people just skip the use of Prop and Berta. There are often problems with them. When they run, they run fine - but there are many people who messes with them, then they can't operate.”* [unpublished]

This was supported by the following statement from a kitchen staff member:

”It's great that the robots can drive all the wagons, but they actually cause more irritation than benefit. Well, it's fine when they work, but often they just don't work. […] Maybe because people tamper with them, the network is down, or something else […] I don't know what goes wrong, but sometimes the robots just don't work and then we call the supplier. If they don't answer, we leave the robots until the next day. We're happy with them when they work, but we want ones that work all the time! We actually need to use the robots again tonight, but we're faster at picking up the wagons ourselves, so we just let them charge.” [unpublished]

4.1.1.8 Summary

Venturing down into the depths of a Danish hospital basement, this study uncovered a several challenges that arose from having robots in the workplace: from changes in work routines to the invisible procedures that caused complications, it was clear that robots were catalysts for complex work changes that needed to be carefully considered. The findings revealed that robots were more than just machines - they were agents of change. A surprising revelation from the exploration was that the mobile service robots in the hospital were not considered reliable enough for critical tasks. In addition, they took up a great deal of space in the hospital basement with the attached carts, disrupting the daily routines of already stretched-thin porters and other staff members. Further, the complex cooperation between the kitchen staff and robots were uncovered and it was observed how the everyday interactions between the two encountered several difficulties: one of the biggest issues was that many procedures involved invisible steps of work, making it difficult for robots and the dynamic work environment to interact effectively. Managers' expectations for robots to simply automate work tasks and procedures were unrealistic in practice, as the robots necessitated changes in work routines, creating a need for a more holistic approach to their deployment.

The study emphasised that if robots are to function in the wild, they must be viewed in broader, ecological terms; as something requiring assistance and support, for the collaboration between humans and robots to flow. Robots and automation are two distinct concepts, although they are often used interchangeably. Automation refers to the process of automating tasks and activities without human intervention, which can include automatic systems performing repetitive tasks, while robots are more complex, can perform a wide range of tasks and work collaboratively with humans or independently. In real-world settings, it is essential to have a co-worker perspective on the robots, as seemingly simple tasks are comprehensive. The research demonstrated that the idealised ability of straightforward automation to handle work tasks and procedures were complex in the given real-world setting.

4.1.2 Further findings from Study I (SHS Sønderborg), published in Paper II

The paper *How socio-technical factors can undermine expectations of human-robot cooperation in hospitals* [2] had the aim of exploring how robots influence the environment they take part in. Earlier research within the field has recognised that robots affect the environments in which they are deployed. This understanding formed the basis on the investigation communicated in the paper; an investigation exploring how robots impacted the environment in a Danish hospital and what to expect when they are released into the wild.

The study discovered that the mobile robots were incapable of adapting to the changes in the hospital environment – changes that humans made to facilitate human-robot collaboration. For instance, the robots failed to follow the designated lanes as expected by hospital staff. This occurred because the robots had to navigate the hospital basement environment, which involved avoiding porters on trucks, pedestrians, cyclists, and obstacles left on the floor. The narrow hallways in the basement brought humans and robots into close proximity, and whenever a robot approached a human, object, or item, its sensors would detect a potential risk of causing harm, leading the robot to immediately halt its actions. These frequent robotic stops resulted in frustration and annoyance among the staff, who were unaware that the robots acted in such a manner to prevent harm to their surroundings. Consequently, the staff's expectations of flawless and autonomous robot performance were revealed to be impractical in real-world scenarios.

As declared earlier in this section, the findings in this paper stems from the same field study as communicated in Paper I, Study I, consequently the methods and the robot characteristics will not be outlined here, as they are mentioned in the section about Paper I. The paper communicated insights on the robots' difficulties in adjusting to the changes made for them in the hospital basement environment; on staff working around the robot rather than collaborating with them and finally; sabotage against the robots is conveyed. Further, the publication identified three factors that influence human–robot cooperation in hospitals: environmental factors, behavioural factors and factors related to human reliance on robots.

The findings of the paper indicated that the cooperation between humans and robots in the hospital environment was fragmented due to insufficient consideration of socio-technical factors. The study highlighted the importance of understanding real-life environmental factors, human reactions and behaviour towards robots in complex non-robotic environments, and the influence of robots on their operating environment [2].

4.1.3 Findings from Study II (SHS Aabenraa), unpublished

In the following, findings from SHS in Aabenraa will be presented, as these are part of the same organisation as the hospital in Sønderborg, which Paper I and Paper II comprised. The two hospitals in Sønderborg and Aabenraa are organisationally under the same administration but located at two different sites. The hospitals operate as separate entities in terms of their physical locations and day-to-day operations, but they share a common organisational structure and management team.

The findings from Aabenraa however, are not published anywhere, as they were deemed outside the scope in the published papers. Further, the data from Aabenraa was limited, as the hospital was under reconstruction and most of the robots were put into their docks, as seen in Figure 26 below, without operating, to make room for workmen, at the time of the field work [unpublished].

Figure 26 Mobile robots standing in docks at the hospital basement at SHS Aabenraa

Moreover, due to the Danish summer holiday, the hospital experienced a decrease in productivity, resulting in limited activities taking place. As a consequence, the amount of data gathered through observations, guided tours and shadowing was limited. However, the data comprised 15 interviews, 11 of them with hospital kitchen staff, who usually collaborated with the robots, two of them with porter staff and finally, two expert interviews with respectively the kitchen manager and the technician who was responsible for troubleshooting the robotic operations, when they encountered difficulties [unpublished].

4.1.3.1 Findings

In the hospital, the robots were installed to run from the basement to the kitchen and from the kitchen on towards different wards in the hospital, sharing elevators and hallways with humans. One of the hospital technicians, who had other tasks as well, was given the responsibility for the eight robots and the daily operation of these. He was the one to answer the phone that hospital staff would call if they needed help with the robots. Furthermore, he was in dialogue with the developers of the robots and could call them to get remote support at any time in real-time.

The robots were programmed to not be in the same zone at the same time. For example, only one robot was allowed into the kitchen at a time, in order to not cause stress or bottlenecks for humans nor robots, as space in the kitchen was limited, as seen in Figure 27.

Figure 27 Limited space for robots to maneuver in the hospital kitchen.

According to the kitchen staff, the robots were a pleasant add-on to their work, as they could save time on transporting items around the hospital, as the robots would do that for them. However, the informants in the study emphasised that the robots would often just stand still in the hallways, seemingly without doing anything. When staff encountered a robot that was standing still, some of them would notify the hospital technician, Lars, who would work out the problems. However, I asked the technician what he did when staff called with robotic errors, and he stated:

> "*For example, they call and complain about four robots that are standing and waiting. And I say, I'll solve it. But you know what? Many times, I don't even need to do anything, and they should just let it be. Let the robots stand still.. After 10 minutes, it solves itself - so - the staff, they have no patience. It's often because the robots are waiting for each other. They just need a chance..*" [unpublished]

Often, there were no technical or functional errors, when staff had called upon the technician, rather the staff was unaware that the robots were waiting for each other to leave the programmed zones, as mentioned earlier. But as the robots were not moving, they would often stand in the way for hospital staff, hindering passage, and consequently causing frustrations, as staff were hindered in performing their tasks. It was a cry for help for them to notify the technician: they were irritated and thought there was something wrong with the robots, as they were not moving [unpublished].

Figure 28 Robot driving in the hospital basement at SHS Aabenraa

In cases where robots were not moving, but simply standing still, it was mostly due to the wait for each other, but in other cases it could be because someone had turned them off, for example to minimise the traffic around the elevator, as hospital staff and the eight robots shared these, around the hospital. It was common for porter staff to press the emergency STOP-button on the robots, forcing them to stop, paving the way for the porters to get their own jobs done, as they experienced much waiting time, when the robots had to use the elevators. When a robot would use an elevator, it would drive up in front of it and wait for it to be empty. It would park in front of the elevator and repeat the Danish words for “Waiting for ‘ready elevator’”. When the elevator arrived and was non-occupied, the robots took charge of it. Consequently, human staff would have to wait for the robot to be done using the elevator, before the humans were able to occupy the elevator themselves [unpublished].

Figure 29 Mobile robot loaded with cart on hospital hallway at SHS Aabenraa

When interviewed, staff members explained that the robots were disturbing their working routines when they were standing still and *did not work*. When staff explicated that the robots "*did not work",* they referred to the robots standing still in the hallways, in most cases waiting for each other. Then, staff would have to wait for the robots, which caused frustrations and delays in their piles of tasks. One of them said that the robots would sometimes cause extremely delay in her and her colleagues' work routines:

"If we have used the robots during the day, and they have been standing still with dirty dishes... Then they come late into the kitchen with the dishes. So, we are behind in terms of getting the dishes washed - to put it bluntly, we can end up with dishes from a whole day, at the end of the day. Then it has to be taken care of by the one person who comes in the evening. It becomes so many dishes that he can't manage to do it all." [unpublished]

Consequently, in some cases the kitchen staff preferred to take on logistics tasks themselves, in order to make sure that they could keep up with their work schedule.

The key finding from the hospital in Aabenraa was that the robots were perceived a great support in the staffs' everyday working routines when they aided, which they did when they were

driving without delays. However, the delays occurred often, resulting in the hospital staff lost trust in the robots. In interviews, the majority of the staff stated that it was pleasant to collaborate with the robots, when the robots worked, but they had become used to the robots being interfered with/turned off, resulting in their low hopes and aspirations in relation to the robots. Furter, they experienced that the robots were often standing still which they interpreted as errors. However, this was a result of the programming of the robots and not a technical error – but the staff was unaware of this and consequently, the lack of knowledge and information, caused frustrations.
It seemed to the staff that they were lucky when the robots performed tasks. This view was supported by the technician, who stated that the staff could not necessarily trust robots:

> *"One might ask me; how can you actually trust that the robots do what they are supposed to? Then, I'll answer that I can't do anything but set them up, take a chance.. And hope it works."* [unpublished]

4.1.3.2 Summary

The findings of this study revealed that in the hospital setting, the robots were installed to assist with tasks such as transporting items between different areas of the hospital. A hospital technician was responsible for overseeing the operation of the robots and providing support when needed. The robots were programmed to avoid being in the same area at the same time to prevent congestion and inconvenience for both humans and robots. However, staff members often encountered situations where the robots appeared to be standing still and not performing any tasks. This led to frustration and confusion among the staff, who would then contact the technician for assistance. Interestingly, the technician noted that in many cases, the robots would resolve the issue on their own after a short period of time. The staff's impatience and lack of awareness that the robots were waiting for each other to move to different zones often led to unnecessary calls for technical support. There were instances where the robots were intentionally turned off by the hospital porters to minimise elevator traffic and allow the porters to carry out their own duties without delays. This further contributed to the perception among staff members that the robots were not functioning properly. The standing robots obstructed the passage in hallways, causing disruptions to staff members' work routines and resulting in delays in tasks such as dishwashing in the kitchen. Consequently, some staff members preferred to handle logistics tasks themselves to ensure timely completion.

Overall, the key finding of the study was that the robots were considered a valuable support in the hospital staff's daily work routines when they were functioning without delays. However, frequent delays and instances of robots standing still eroded the staff's trust in the robots. The staff had become accustomed to the robots being interfered with or turned off, leading to lowered expectations and diminished confidence in their capabilities. The lack of understanding regarding the programming of the robots further fuelled frustrations among staff members. Trust in the robots was limited, and reliance on their performance was uncertain, as expressed by the technician.

4.1.4. Findings from Study III (OUH), published in Paper III

In the third paper, *Understanding human-robot teamwork in the wild: The difference between success and failure for mobile robots in hospitals* [3], the aim was to explore the collaboration between humans and robots in hospitals deeper, as the findings from the study communicated in Paper I and Paper II had revealed the need to investigate hospital staff-mobile robot collaboration, including the teamwork between the parties, further. This was done by scrutinizing the field at another site, Odense University Hospital (OUH), where the two robots AMR's, Hubot and Hubot2, were deployed to transport samples around the hospital. In the following, the robots will be referred to as *The Hubots.*
It turned out that the collaboration in this hospital, was quite different from the first hospital and consequently, Paper III discusses the insights from the two different hospital cases against each other. Although both hospitals had implemented mobile robots with similar goals of assisting staff and improving efficiency in logistical processes, the way these robots operated, their task performance, and overall outcomes differed between the two hospitals. The differences originated, among other things, from varying division of responsibility for robots and differences in environmental infrastructure: in the first hospital, SHS, there was no clear division of responsibility for the robots, for example there was no dedicated person to take care of errors, while in OUH, the responsibility was clearly assigned to the Technical Manager. Further, the environment in the first hospital was not well-suited for robots to take part – or collaborate with humans – in, while the opposite was the case, at OUH.

The methods utilised in the study were identical to the ones in the first study, comprising observations, interviews, and guided tours. The primary method of data collection was participant observation, where I closely observed the teamwork between hospital staff and robots to gather information and insights. I followed the two Hubots around throughout the hospital, as they completed their daily tasks and interacted with staff members, which resulted in detailed, descriptive field notes, photos, and audio and video recordings, produced contemporaneously with the events and interactions they captured. In addition to participant observation, data was also collected through 20 on-site interviews with Medical Laboratory Technologists (MLTs), who were the primary collaborators with the Hubots. The Interviews were utilised as a mean to acquire an in-depth comprehension of participants' experiences and viewpoints, crucial for obtaining a comprehensive understanding of the collaboration, routines, and work practices between staff and robots. In addition, data was collected through guided tours of the hospital and an expert interview with the hospital's Technical Manager (TM) who was responsible for the Hubots. For further details on the methods, see Paper III, section *III. Methods* [3].

4.1.4.1 The robots

The Hubots were constructed by the hospital's Technical Manager (TM) using spare parts and materials he had available in his office, colloquially called the Robot Garage or The Lair. He had built the Hubots on top of MiR200 mobile robot bases. Hubot, the largest and oldest of the robots (see Figure 30), was built by adding a cabinet where blood samples could be stored during transport, in three baskets, as seen in Figure 31.

Figure 30 The mobile robot named Hubot, at OUH

Figure 31 Smartphone attached to Hubot

Figure 32 A look inside Hubot while the robot is waiting in the hallway for a MLT to load samples into its baskets

Hubot2, the smaller, new robot, had a single box for storing blood sample racks, as seen in Figure 34. Both robots had a lock, emergency stop button, and smartphone attached for hospital staff to control their operations, including locking/unlocking, stopping, and sending them on missions.

Figure 33 Hubot2 waiting in the hallway
box to be loaded with blood samples

Figure 34 A look inside the robot Hubot2's
for storage

The robots transported samples around the hospital in fixed routes, illustrated in Figure 35.

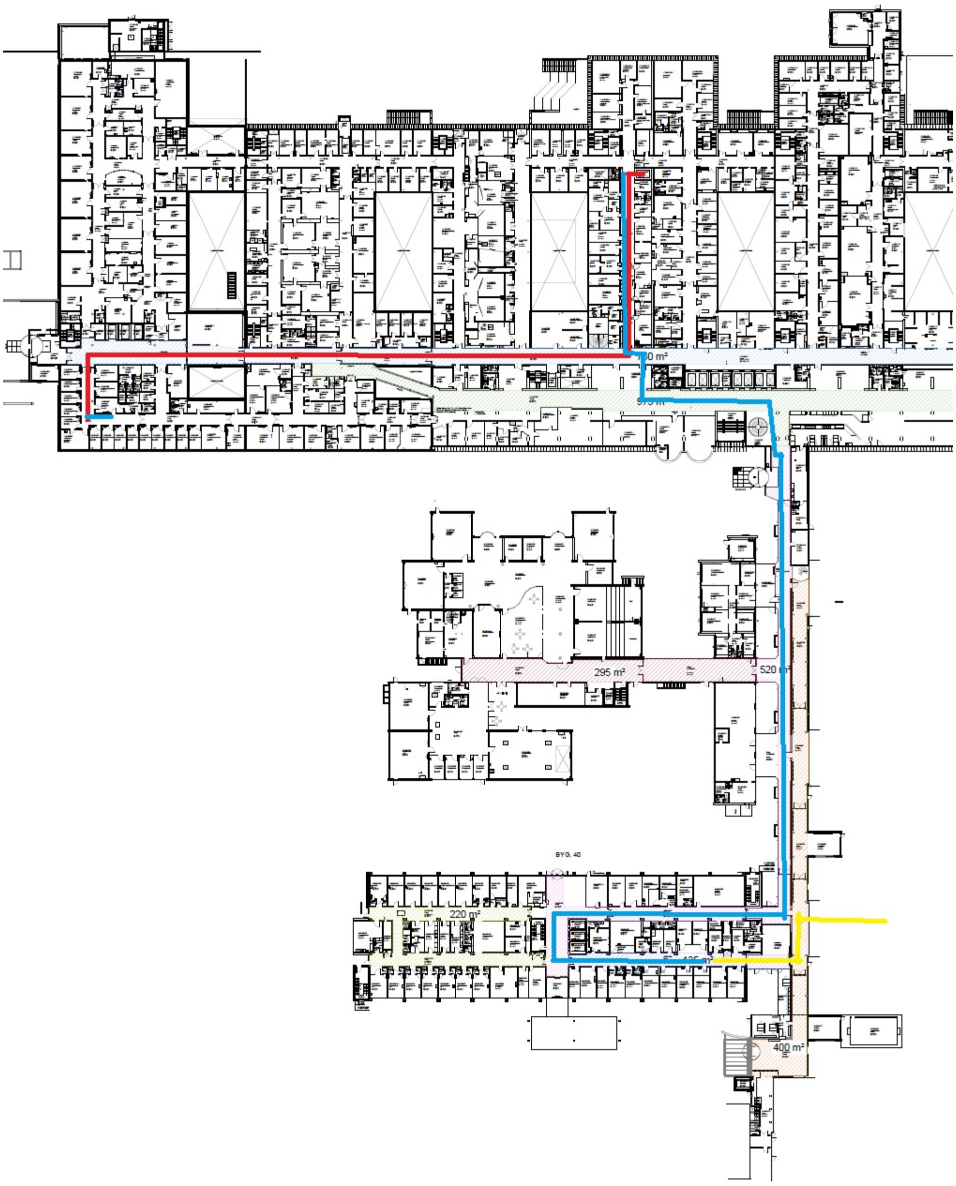


Figure 35 Overview of the robot routes in ground floor of the hospital [3]

The red and blue lines respectively denote the routes taken by Hubot and Hubot2. Hubot collected blood samples from Clinical Genetic Ambulatory Unit located on the first floor and transported them to the laboratory on the ground floor of the hospital. Hubot2 collected blood samples from the children's hospital on the first floor and transported them to the laboratory on the ground floor. The robots had designated stopping points in the hallways where they would wait for further instructions, after they had accomplished what they were sent off to do.

The robots used the same elevator as staff to travel between floors. In order to do so, the robots positioned themselves in front of the elevator and waited for 15 seconds of inactivity before taking control of it. Due to frequent use by the staff, the Hubots often experienced long waiting times for the elevator, but once a robot had control of the elevator, it could not be controlled by a human - they had to either wait for the robot to complete its ride or accompany it. However, the Hubots parked in the center of the elevator, leaving limited space for a human to join, which could cause frustration for the staff [3]. One of the MLTs stated:

"I just find it really annoying when I am about to enter the elevator and think YES, there's no robot; but then the robot is standing right here, inside the door. If you're only going in alone, it's okay - but if you need to bring in a trolley; forget it. It could just drive into the corner, then there would be plenty of space, right? And I don't understand why it can't turn while the elevator is moving, like... Sometimes it takes so long to figure out how to turn around that the door closes." [unpublished]

The MLTs stated that the robots, in some cases, would take a long time to ride the elevator, causing bottlenecks and work slowdowns. However, the MLT's were pleased with the Hubots, as felt through this:

"I think it's very good! It's a useful tool, in my opinion. It makes it a lot easier to move things around. It's very easy to use." "What do you think of the Hubots? Do they take up a lot of space here?" "No, they don't take up much space and they're good at manoeuvring around. You quickly get used to them being here too. At first, I was like oh, he's coming right there.." he says and jumps a little to the side *"and then you had to make room, but they're good at manoeuvring around, I think. I don't experience any major problems. Hubot never bumps into us, it's probably more us who accidentally bump into him because we didn't see him. It's not him who ran into us, it's us who ran into him."* [unpublished]

4.1.4.2 Staff-robot collaboration

The robots were driving for quite long distances through a workday, approximately 7-8 kilometres. Figure 37 provides an example of an excerpt in Hubot's daily routine.

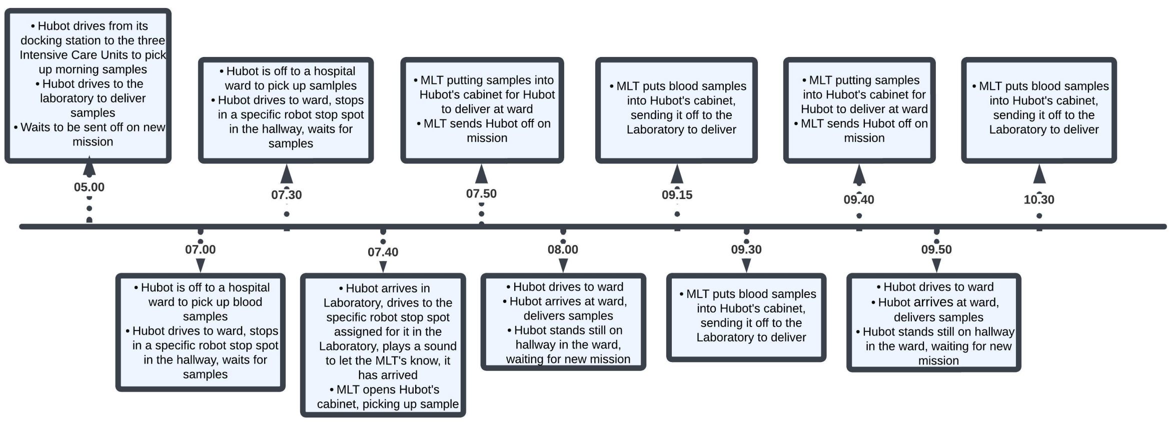


Figure 36 Example of a morning in the life of Hubot [3]

The figure depicts the activities of Hubot, beginning its day at 5 o'clock by departing from its docking station located in the Hospital Laboratory and proceeding to the Intensive Care Unit to collect samples. It then travelled to the laboratory to deliver the samples before embarking on another mission. This cycle continued throughout the day until 16 o'clock when Hubot returned to its docking station, preparing for a new day [3].

Figure 37 The mobile robot named Hubot2 or Little Hubot driving in the hallway of OUH, approaching an elevator

Figure 38 Robot in charge of elevator, at OUH, hence the symbol

Figure 39 Robot drives into elevator at OUH

As stated in Paper III, the human-robot collaboration in the given hospital, was carried out between different staff groups: there was one kind of HRC between the TM and the Hubot, and another type of HRC between the MLT's and the Hubots. These two formations constituted two different teams: Team HTM (Hubots + Technical Manager) and Team HMLT (Hubots and Medical Laboratory technologists). In Team HTM, the TM assumed the role of caretaker for the robots and possessed a vast, comprehensive knowledge and understanding of them. As mentioned, he had partially constructed them with materials he found within the hospital premises and over time, programmed, adjusted, and refined the robots to fit the hospital environment and cater to the needs of the people around them. The Technical Manager was well-known among hospital staff as the person in charge of the robots and was responsible for training and educating them in how to use the robots.

Further, he had programmed the robots to interact with people they encountered politely, and to give directions such as *"Please step aside"* or "*Keep to your right when you walk the hallways"* in his voice, warning the surroundings that a robot was approaching. The TM had a neutral and objective bond with the robots, addressing them in the neuter form. His mission was, that the robots would operate unnoticed and thereby avoid bringing frustrations to hospital staff, as it could lead to difficulties and non-use, and he had a rule: if an error was detected, he would have had to begin troubleshooting within 5 minutes.

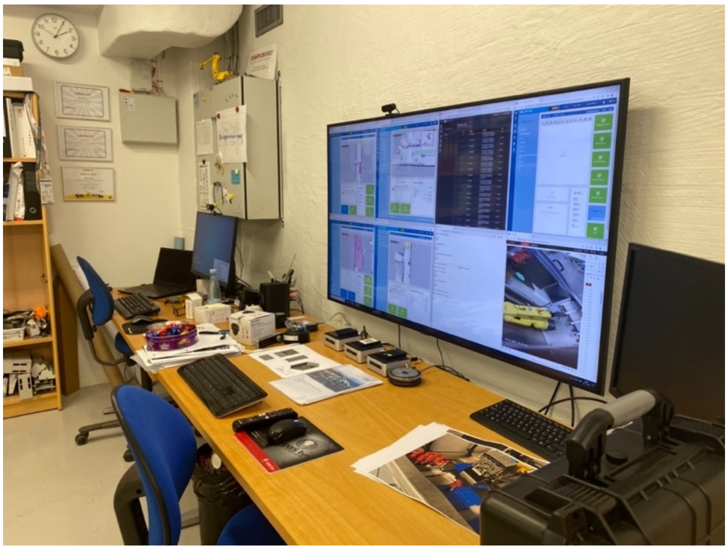


Figure 41 The Technical Manager's desk with screen to monitor the robots on, in the den in the hospital basement at OUH

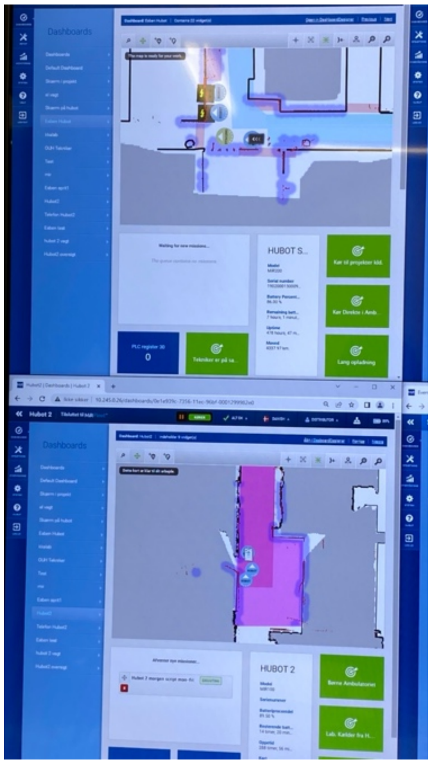


Figure 40 Example of the display on the Technical Manager's monitoring screen

Otherwise, robotic errors could potentially lead to staff dissatisfaction and negative perceptions towards the robots, ultimately leading to their abandonment. To accommodate his own mission, the TM constantly monitored the Hubots using various devices, such as tablets, smartphones, and computers, providing him with a real-time overview of their activities, which enabled him to detect any errors that may occur [3].

The Technical Manager had a range of tools to support the robots, which he could access remotely using an internet connection, resulting in minimal downtime. He stated:

In 95% of cases, I just take out my phone and handle whatever needs to be done. It's smart. As long as there's internet, it works. Sometimes when I'm in Italy, they call me and ask for help to get the robot working. And that's great! It also reduces our downtime because I can always access it. They have logs, so I can see everything, all the missions that have been queued up. For example, here you can see the latest mission took 6 minutes, which we just watched, it ran in the Ambulatory down from the lab. I can go in and expand on the mission. If there's anything wrong, I can go in and see what it is. But as you can see here, first it received the mission, then it calculated if it had enough battery, then it accepted the mission. And then I have set up that if there's less than 30% power, it should go to the charger. Then it goes on its own. The chargers are down in the lab. During a workday from 7-16, it just needs 10 minutes of power, and then it can run all day. [unpublished]

The responsibility for the Hubots was solely taken on by the TM and every staff member knew that they could reach out for him if they encountered difficulties with the robots. This would ease the troubleshooting process. The MLT's, the team being aided by the Hubots, were not responsible in any way and consequently they found it easy to collaborate with the robots, not least as they knew that the TM was monitoring the robotic operations and would troubleshoot, if something went wrong. The Hubots supported and aided the MLT's by carrying blood samples for them, around the hospital. Team HMLT was characterised by the Hubots being an aid and helping hand throughout the MLT's day and the MLT's were reliant and dependent on the actions of the Hubots, carrying samples for them to analyse. The MLT's could order porter staff to transport samples and would in some special cases have to do so, but it was primarily the robots that performed that task, which was their primary function. According to the MLT's, it was more efficient to use Hubots than to overburden the service staff group. In addition, the MLT's considered the Hubots as great supporting tools that were easy to use:

"I think it's wonderfully easy! It's straightforward, there's no need to stand around and think for a long time [...] we can easily let it stand and finish what we're doing - and then go over to empty him." [unpublished]

As seen in this quote, the MLT's are addressing the Hubots as male, which was a general approach across staff groups, as the following scenario also bears witness to:

I stand in the hallway while an MLT empties Hubots cabinet for samples and says:

'Thank you for that, Hubot - yes, he is very compliant', then she leaves. The cleaning lady, standing next to me says 'Yes, but we just have to keep an eye on him all the time and help him.'

Just as she had said that another female MLT passed by and laughingly said:

'Yes, but he is a man, you know!' [unpublished]

The HMLT team's relation to the Hubots was indirectly influenced by the HTM team, as the MLT's personalised the robots and interpreted them and their actions, programmed by the TM. For example, the TM had programmed the robots to stop when they got too close to a human, which the MLT's interpreted as politeness, as one of the MLTs stated:

" It's not him running into us, it's us running into him. He's too polite!" [unpublished]

The Hubots were deemed useful by some MLT's, who found them to be a relief from tedious tasks. One MLT described Hubot as a capable individual who could perform menial tasks, while another stated that collaborating with the robots was pleasant. In general, Team HTM played a crucial role in supporting Team HMLT, as the Technical Manager was responsible for ensuring the smooth functioning of the Hubots. While the Hubots received assistance from human personnel in Team HTM, they served to provide support and aid to their human counterparts, in Team HMLT [3].

Throughout the field study it was clear that the Hubots were great in supporting the MLT's and the TM was great in supporting the Hubots. This was supported by MLT statements, such as:

"Sometimes, the robot gets stuck in the elevator. But then we'll just call Esben, and he is there, fixing it, right away." [unpublished]

and

"*[...] sometimes they [the Hubots] can get a little carried away down by our elevator - but then we have our Esben, so we just call him, and everything works again immediately."* [unpublished]

The success of Team HMLT was largely dependent on the operations of Team HTM and the findings of the study reveal how a clear assigning of responsibility of the robots was key to ensure that human-robot collaboration in hospitals could fulfil the aims they were formed on the basis of. Thus, it is vital to assign resources to onsite, holistic robot support in hospitals, preferably to someone who is dedicated and responsible for the daily robot operations. If the robots are to succeed in collaborating with hospital staff in unstructured environments, it is crucial that the troubleshooting processes are specified and it is important to sharply define and delegate tasks between humans and robots to eliminate any confusion or uncertainty about when (or if) to utilise the robots [3].

Figure 42 The mobile robot Hubot driving among patients and staff in the hospital foyer at OUH

Another key finding in this study was that the environment shared by robots and humans was well-suited for the robots to perform their tasks, as the areas in which they operated were wide spaces, at OUH. The narrow hallways in the basement, where service staff drove large and fast vehicles and traffic was mixed, were deemed unsuitable for robots, by the TM. When asked if the hospital had robots in the basement, he stated:

"No no no, we don't, it wouldn't work at all! Primarily because of the trucks, but also because the corridors are too narrow for robots. We've also done some testing and it just doesn't work." Then, he showed me trolley and said that if a truck came driving next to the it, and there was also a robot, there would be no room for either of them. "[...] down here, there are trucks that drive very fast, beds that take up space, trolleys and cyclists, all sorts of things - it doesn't work to have robots in a place like this." [unpublished]

Figure 43 The mobile robot Hubot2 driving in the hospital hallway at OUH

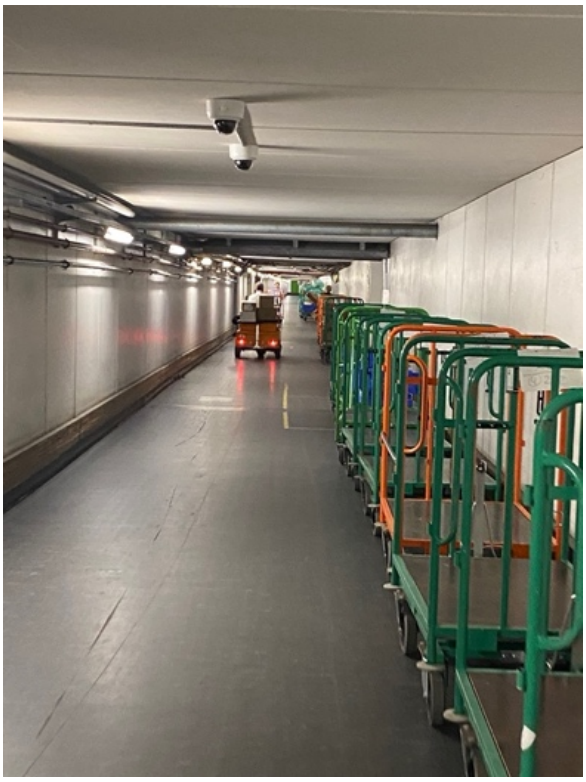


Figure 44 The hospital basement at OUH, deemed a crowded, busy setting – too busy for robots to fit into

Consequently, the Hubots were confined to the ground and first floors where the hallways were wider. The robots were installed in areas where they were able to move around without much notice, supporting staff who trusted them to perform assigned tasks. This, while SHS had installed robots in the narrow hallways of the hospital basement where there was heavy traffic. In both cases, the robots were designed to operate in areas where humans were walking. However, in the hospital in Sønderborg, the narrow hallways caused the robots to frequently stop when they came close to humans or other obstacles, blocking passage and causing frustration among hospital staff. The slow pace of the robots also impeded the work of the porters who were unable to get around them on their trucks, resulting in a vague and difficult teamwork between staff and robots.

The study findings suggests that to ensure successful collaboration between humans and robots, the environment must be suitable for both parties. If it is not conducive to the movement of both humans and robots, it can lead to difficulties in performing tasks, resulting in frustration and even sabotage. However, when the environment is well-suited for both humans and robots, the teamwork between them will flow better. This must be combined with a dedicated onsite robot manager, to support the daily robot operations [3].

When the vital infrastructure is in place, humans collaborating with robots can find the surplus energy to ascribe the robots particular qualities and characteristics and personalise them, which develops the relationship and teamwork between the parties, making the bond between humans and robots stronger.

Figure 45 The mobile robot Hubot decorated for Christmas.

Once the essential infrastructure is established, humans working together with robots can find the extra energy to attribute certain qualities and traits to the robots, as well as personalise them. This fosters the relationship and teamwork between the two groups, resulting in a stronger bond between humans and robots. This came to appear when the MLTs' decided to decorate one of the robots, Hubot, for Christmas. They decorated the robot they had collaborated with for longest time and when asked why they decorated the robot, the answer was:

"*It only means we love him [Hubot], that's all!*" [unpublished]

The relationship between the MLT's and the robot that they had had for four years, seemed stronger than the bond between the MLT's and the newest robot. When asked if the new robot should also be decorated, the same MLT stated:

"I don't know if we dare, because there have been all these problems with the hygiene nurses, soooo... I also don't know how Little Hubot feels about Christmas decorations." [unpublished]

When asked whether there had not been any difficulties with the hygiene nurses and Hubot, he answered:

"We're not talking about that, soooo," [unpublished]

and laughed.

Apparently, the MLT were more likely to ignore restrictions when it comes to Hubot, than when it concerns Hubot2. In addition, during the expert interview with the TM, he stated that he was very critical of the Christmas decorations on top of the robots, and had often removed them, to remind the staff that the robot was a serious agent that carried important blood samples in a hospital – not a pet or a toy. The MLT's however thought it was cosy that the robot had Christmas decorations on top, they would smile at it, laugh together about it and approach it with phrases such as "*Merry Christmas, Hubot.*" and continuously decorate the robot, throughout the Christmas season [unpublished].

4.1.4.3 A pragmatist in the hospital

Figure 46 Scooter parked in the hallway at the spot where Little Hubot hit it.

One of the findings not included in the paper is that the robots were causing minor trouble in the hallways, as they were unable to detect objects below a certain height. The TM was aware that the robots were unable to do so, however he was not aware that it had an impact in the hallways, which became clear, as I followed the Hubots around. I observed how Hubot2 drove straight into a stand with hand sanitizer and pushed it along. Furter, I was approached by mail delivery staff, who told me that Little Hubot was being tricky with her scooter, when she placed in the hallway. She stated that one day, she had parked her scooter next to the trash bins, as close to the wall as possible (see Figure 46) to not cause clutter in the hallway, and then left to deliver a letter in a ward. When she returned, the scooter was overturned, lying on the ground and the letters she had left in the scooter basket, were spread all over the floor. She told me that eyewitness tales had told her about how the little robot had knocked the scooter over, causing letters to whirl and spread and then left the *crime scene* and wanted to ask me if I could help her make sure that "that thing" (as she called the robot) would stop knocking over her scooter. It turned out that she had experienced a few times that her scooter had been knocked over and the letters were scattered all over the hallway when she returned to it after having ran an errand. She told me that when it happened, she went to the Children's Hospital (where the robot was driving from) and asked them to get "that thing" under control. However, for some reason the issue continued. Based on the pragmatist research approach in this study, I verbally and informally outlined the issues for the TM and provided actionable recommendations. The recommendations consisted of informing the robots about the objects, so they would drive around them, and to make sure stuff that could interfere with the robots would be moved. The TM right away reprogrammed the zones in which the new robot was allowed to drive, making it unable to drive close to the walls in the spots, where I had referred the issues to be. A couple of hours later, I realised how the recommendations had had an immediate impact on the objects placed on the robots' routes, as I met a MLT outside the elevator [unpublished]. He was removing a handcart that had been standing in a place where it would be in the way of the robots and said:

"I was just told it can't be there. Apparently it has something to do with this loading ramp, it's too low for the robot to see it and it could knock it over. It's something new, I was only just told about it now." [unpublished]

4.1.4.4 Summary

The findings from this study show that the division of responsibility for robots and differences in the hospital environment significantly impacted the robot performance and the possibilities for successful HRC at OUH. The Technical Manager played a crucial role in the successful operation of the robots, providing support and troubleshooting, hence the study highlights the importance of clear responsibility assignment and dedicated robot support for effective human-robot collaboration in hospitals.

4.1.5 Findings from paper IV

In the following, the findings addressing the research question, *What are key elements in a conceptual framework for HRC at work in hospitals?*, are presented.
In the fourth publication entitled *A scoping review and conceptual framework for understanding human-robot collaboration at work in hospitals* from this PhD project, newer research upon HRC in hospitals was investigated thoroughly, to scrutinize recent knowledge within the field. The scoping review is conducted according to the PRISMA-ScR guidelines, considering 17 articles eligible. These were analysed thematically and the collaboration between mobile robots and hospital staff were categorised into five themes, respectively: Using mobile service robots in hospitals; Barriers/Facilitators; Social aspects; Acceptance/adoption; Opinions/perceptions. In the discussion, the newer findings identified in the review were discussed and combined with elder findings from this field, enhancing the understanding of HRC in hospitals, and resulting in a conceptual framework for understanding HRC at work, in this setting. The framework comprised seven elements, respectively: environmental factors; attitudes; opinions/perceptions; social aspects; teamwork/relationship; acceptance/adoption; and trust [4].
The newer findings, and the conceptual framework will be outlined below.

4.1.5.1 Using mobile service robots in hospitals

According to the scientific studies, mobile robots are employed in hospitals owing to their ability to perform tasks in lieu of humans and operate closely with diverse categories of workers. By taking on simpler responsibilities, they enable hospital staff to focus on more complex work, aid in easing the burden of daily routines for employees, address understaffing concerns, minimise workloads, and optimise operational efficiencies [4].
Mobile service robots are utilised in hospitals for efficient cleaning, patient and supplies logistics, minimising human errors, and remote monitoring of patients. By leveraging the capabilities of mobile service robots, hospital personnel can offload certain time-consuming tasks such as the transportation of goods over longer distances and allocate their attention towards other pressing duties. These robots have the ability to deliver items such as samples, meals, linen, medicines, medical supplies, and packages with minimal reliance on human intervention. By taking over delivery tasks that are typically limited by factors such as time, mobile robots have the potential to change hospital logistics. By reducing the need for human scheduling constraints, deliveries facilitated by mobile service robots can become more efficient and adaptable. Furthermore, mobile service robots can take on repetitive and routine tasks, resulting in increased efficiency, task consistency, and uniformity in performance [4].

4.1.5.2 Barriers

The scoping review found that the introduction of robots into hospitals is a complex undertaking, primarily due to the intricate and multifaceted nature of the healthcare environment and identified potential barriers to implementation.

One of the barriers, is the design of the robots as they are often designed for specific environments, with many mobile service robots developed for use in highly structured industrial settings, where movements and processes are meticulously planned, and workers are trained to collaborate with robots. Conversely, a hospital environment is characterised as unstructured, unpredictable, and complex. Consequently, when robots are deployed in hospitals, staff face several challenges in working alongside them, which can result in suboptimal functioning of the robots. In addition, a significant challenge to successful HRC in hospitals is the issue of space, as mobile robots can occupy a substantial amount of room in hospital hallways, limiting the space available for human workers, which can cause frustration among workers who must share the workspace with the robots.

Another barrier for HRC in hospitals is reliability, as robots can be perceived as unreliable in task performance and consequently not assigned critical tasks. This can result in altering the workloads of human staff, as they in some cases will have to perform tasks assigned for the robots and further will be tasked with new responsibilities, such as caring for the robots and make sure obstacles are removed from the robot route, allowing them to drive.

A further barrier is the lack of practical abilities and safety concerns among hospital staff, as they may doubt their technical skills and experience doubts about their technical abilities and feel apprehensive about their safety when engaging in collaborative work with robots, a situation that is often attributable to a lack of knowledge and expertise in using such technology. Additionally, training and education in the use of robots can be discouraging for hospital staff, who may reject the idea of using them if the required guidance is overly demanding. Furthermore, the integration of robots into healthcare systems may face obstacles since humans may perceive them as a potential threat, further compounding the complexity of an already intricate environment [4].

4.1.5.3 Facilitators

On the contrary, successful HRC in hospitals can be achieved through proper training and education of staff, resulting in increased knowledge, competencies, and acceptance of robots in their workplace. According to the findings in the scoping review, organisations interested in deploying robots must educate relevant personnel, promote their ownership of the technology, and ensure that they act as ambassadors for mobile service robots in hospitals, by spreading positive messages. It is also essential to assess existing hospital workflows and analyse their potential impact on the human-robot collaboration, both directly and indirectly. Such an overview and analysis will allow for designing human-robot workflows appropriately to support human hospital workers. Further, successful deployment of robots in hospitals depends on the human, robot, and organisational dimensions. The human dimension encompasses user acceptance and ability, while the robotic dimension includes robot capability and tailoring robots to the users' needs. The organisational dimension covers leadership and well-planned deployment of robots in hospitals. Moreover, ensuring and anchoring technical robot support within the organisation is critical in facilitating HRC in hospitals [4].

4.1.5.4 Social aspects

Although mobile service robots are typically designed for industrial purposes and have unresponsive appearances, they can still function and be perceived as social. However, their appearance has a significant impact on the interest and trust between humans and robots, especially in hospital settings. In the review, it is described how mobile robots deployed in a hospital, given the ability to speak in a local dialect, led to increased identification and stronger emotional connection between the humans in the hospital and the robots. The use of such dialect was perceived as cosy, slow, and friendly, projecting the robots as clumsy but personable, and not associated with a high socio-economic status. In contrast, therapeutic robots are designed explicitly to be social and interact with humans. Therefore, scrutinizing the social aspects of human-robot collaboration in hospitals highlights the need to consider the appearance and design of robots to foster trust and engagement with patients and hospital staff.

Further, the workspace shared between humans and robots is a critical social factor that influences HRC in hospitals. In a study included in the review (Paper II in this PhD project), hospital staff attempted to prepare the work environment for mobile robots in advance of their deployment, but the robots' inability to navigate around obstacles such as clutter and narrow hallways caused frustration for both the staff and the robots. This frustration was further compounded by the robots' tendency to slow down work and hinder task completion, leading some workers to sabotage the robots. For example, the robots' elevator overriding capabilities combined with a lack of situational understanding led to delays and waiting times for hospital staff. Such delays can be fatal in hospital settings, where time is a crucial factor. Therefore, social factors in the environment must be considered to ensure that robots can function effectively in the workspace shared with humans [4].

4.1.5.5 Adoption and acceptance

The successful deployment of robots in hospitals depends on user adoption and acceptance. It is crucial to understand the dynamics between humans and robots, as well as user expectations and interactions in various situations. Robot adoption involves three dimensions: technological, human, and organisational, each of which requires intense focus. Failure to address the complexity of deploying robots in hospitals can reduce their potential benefits, as seen in cases of unsuccessful technology development due to the lack of emphasis on socio-technical factors. The technological dimension includes design, technical issues, system reliability, and compatibility, while the human dimension entails trust, perceived usefulness, ease of use, confidentiality/privacy concerns, attitude, and confidence. The organisational dimension involves legal, security, cost, interoperability, recruitment and training, and appropriateness of relevance for processes. These factors must be considered when integrating robots in hospitals. Adoption may be slow due to various reasons, such as the need for state-of-the-art technology, new infrastructure for robot installation, training and knowledge to operate, concerns with human acceptance, lack of trust in new technology, high installation and maintenance costs, and the need to hire personnel to maintain hardware and software related to robot mechanisms. Healthcare problems are open-ended and require robots to learn and adapt spontaneously to different people, tasks, and care settings. The complexity and interdependencies of HRC in hospitals highlight the need to consider a range of factors for successful deployment. Hence, socio-technical factors play a crucial role in the successful adoption of robots in hospital environments. Consequently, it is necessary to consider the robots in relation to their intended operating environment and to have realistic expectations towards their capabilities.

Integrating technologies in human social settings can be challenging due to issues such as sensor interference and environmental clutter. For robots to be usable and accepted in hospitals, it is essential to consider the broader ecosystem rather than just the users who will cooperate with and benefit from the robots. Further, individuals without prior experience in cooperating with robots tend to hold negative attitudes towards them. Such individuals tend to rely on imagination and social representations of robots, which can influence their attitudes towards them. Additionally, the acceptance of robots by hospital staff depends on their perceived usefulness, ease of use, and relevance to their work. Furthermore, a study found that age did not affect hospital staff's perceptions of robots in hospitals [4].

4.1.5.6 Opinions and perceptions

Hospital staff can perceive service robots as both advantageous and disadvantageous. One of the advantages of having service robots in hospitals is that they can relieve staff of exhausting routine tasks and provide them with time to carry out other activities, such as taking care of patients, rather than walking around the hospital with documents. The use of robots can increase job satisfaction, thereby preventing staff resignations. Hospital staff also express that robots are attractive to hospital visitors who find them interesting and become distracted from the realities of the hospital by watching robots. Several papers reviewed suggest that service robots can enhance hospital productivity and reduce overtime working for certain staff groups, who can then use their time to improve their skills through online courses. Although complex tasks are better suited for human staff, robots can be useful in fulfilling routine activities, such as delivery, pulling objects, and performing hazardous and unsafe tasks. Hospital staff desire robots to take on more complicated tasks in the future, and the ability to communicate interactively must be developed. In Sadangharn's work, hospital staff tend to have positive perceptions of medical service robots and high expectations towards them. In the study by Lee et al., hospital staff had high expectations of robots acting as guides in the hospital but low expectations towards the robots in analysing and improving depression or stress among patients. The same study showed that nurses had higher expectations for the use of robots than doctors. According to previous research, hospital staff perceive service robots as having both advantages and disadvantages. Advantages include relieving staff of routine tasks, increasing job satisfaction, and enhancing hospital productivity. However, disadvantages include the lack of human sense and the inability to catch human feelings, as well as the inability to use elevators or stairs. Hospital staff emphasise that robots are better suited for routine activities and hazardous tasks. Hospital managers are found to have the greatest influence on technology acceptance during and after implementation. The disadvantages mentioned by hospital staff can lead to no improvement in service quality [4].

4.1.5.7 Framework for understanding HRC in hospitals

Based on the findings in the review, a conceptual framework for understanding HRC at work in hospitals, was created. This was done by combining the findings from the review with findings from existing studies within the research field, respectively human trust and attitudes towards robots in hospitals; the working environment's impact on hospital staff perception of robots; the working relationship between humans and robots and factors influencing human-robot teamwork. For elaboration of these, see Paper IV. The goal of the combining the findings from this review with existing findings, was to contribute to the cumulative advancement of knowledge in the field. Further, to identify knowledge gaps in the existing literature, allowing my work to build on existing knowledge and be positioned in the extension of knowledge within HRC. In addition, integrating the findings from the review with previous research, a broader context is provided, demonstrating how the findings from the review contributes to existing knowledge and understanding in the field [4].

The conceptual framework presented highlights seven core elements that influence HRC in hospitals: environmental factors, attitudes, opinions/perceptions, social aspects, teamwork/relationship, acceptance/adoption, and trust. These elements are interdependent and can act as both facilitators and barriers to HRC. The framework suggests that to achieve the ideal of robots functioning as partners for hospital staff, rather than just tools, these seven elements need to be considered and addressed. The bases influence each other in various ways and cannot be considered in isolation. Researchers and practitioners can use this framework as a starting point to develop new understandings and theorise about HRC in hospitals [4].

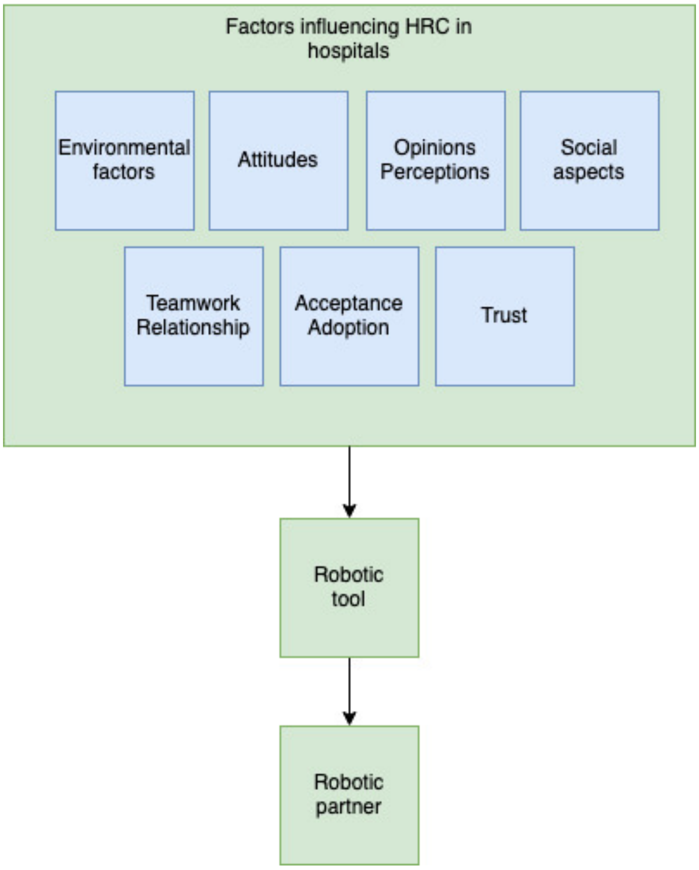


Figure 47 Framework for understanding HRC in hospitals [4]

The framework is a starting point for understanding the key elements for successful human-robot collaboration in hospitals, but it requires further research and testing to become more comprehensive. Incorporating the seven elements when examining HRC in hospitals can potentially facilitate appropriate development, implementation, and use of robots in hospitals, minimizing gaps arising when humans and robots interact and collaborate in unstructured environments. Utilising this framework for future research can lead to new understandings and theoretical developments on the collaboration between humans and robots in unstructured environments, drawing on the existing body of knowledge within the field [4].

4.1.5.8 Summary

The review study provides valuable insights and knowledge on the topic of HRC in hospitals. The consolidation of scientific research and identification of key elements for HRC in hospitals, along with the creation of a conceptual framework for understanding the topic, can serve as a starting point for nuanced discussions on requirements and qualifications prior to deploying robots to collaborate with humans in hospitals. The framework can also be used throughout the lifespan of a mobile service robot collaborating with hospital staff. Additionally, the results can support researchers within the field and provide a foundation for future research.

5 DISCUSSION

The findings have shown how robots caused challenges in work routines and the nature of tasks in hospitals. Further, it was observed how hospital staff lacking understanding of the robots' behavior got frustrated when the robots slowed down the humans' pace of work, highlighting a need for staff to possess knowledge about the robots, they are to collaborate with. Contemplating robots as a simple plug and play automation solution can cause difficulties in real-world environments, as this setting is unstructured and processes more complicated than they may seem, to developers, managers and policy makers. Thus, it is beneficial to dedicate the responsibility for robot operations to engaged personnel who will make sure that the robots function smoothly. If not, the robots will create new challenges of the same nature they were expected to solve and remediate. On the contrary, if robots are maintained and cared for, they can aid and relieve humans by performing tasks, in this case transporting items around hospitals.
In addition, mobile robots need a certain amount of space for operating, thus the environment must be suited for robots. In addition to environmental factors, attitudes, opinions/perceptions, social aspects, teamwork/relationship, acceptance/adoption and trust, are influencing the collaboration between hospital staff and mobile robots and must be acknowledged if robots are to be considered as partners in collaboration, rather than tools.

As stated earlier in this thesis, Danish hospitals are increasingly using robotics technology to automate, support and alleviate the workload of staff and the visions for automating tasks with robots are that certain robots may perform tasks better or faster than humans, take over trivial tasks, and relieve employees. The primary expectation is that robots will ease the workload and save time for the staff, who can use the freed-up time for other tasks. However, as seen in the Findings, it can lead to challenges when robots completely or partially take over procedures in hospital logistic flows.

Research within this area is scarce, although knowledge and understanding of respectively how hospital staff perceive and experience robots; and how robots affect work, both in terms of tasks and in terms of organisational changes, is crucial to hold, when robots are being deployed in hospitals, to support human staff. Thus, the political and managerial visions and expectations towards robots and automation in hospitals could benefit from knowledge upon the actual realisation of robots and automation in hospitals.

This PhD project has generated knowledge upon these subjects, specifically in relation to mobile robots and hospital service staff, in a Danish context. Hence, the following chapter discusses the following:

- Hospital staff experiences with mobile robots, including the dynamics and the relationships between the parties and how they influence each other - and how collaboration is practiced.
- How robots affect work, including a focus on tasks and the organisational changes.
- The synergies between the politicians' and hospital managements' ideas and interests.

In this chapter, the PhD study findings will be discussed drawing upon theories, concepts and related work. The concept of zooming in and out, inspired by Nicolini's framework, will be utilised to frame the chapter [124]. By zooming in on hospital staff experiences with mobile robots, including their experiences, perceptions, and interactions with mobile robots, light will be shed on the dynamics and relationships between the parties. This includes exploring how humans and robots influence and shape each other's behaviours, attitudes, and work practices. Zooming out, robots' effect on work processes and tasks within the hospital environments will be scrutinised. This broader perspective will involve examining the organisational changes and shifts in roles and responsibilities that occur as a result of incorporating robots into the work setting. This will provide insights into the transformative potential of robots as agents of change in hospital workforce. Additionally, the synergies and alignments between the ideas and interests of politicians and hospital managements regarding the implementation of robots in hospitals – and the actual realisation hereof - are discussed. This perspective will involve exploring the political and managerial expectations surrounding the integration of robots, including policy initiatives and decision-making. By examining the interplay between political agendas, organisational goals, and real-world implementation, the discussion seeks to explore the complexities and challenges associated with deploying robots in hospitals. Utilising the framework will provide a comprehensive understanding of the multifaceted dynamics between humans, robots, and work practices in the hospital context. Further, it will enable a detailed exploration of individual experiences and interactions, while considering the broader organisational, societal, and political dimensions that influence the adoption and implementation of robotic technologies in hospital settings.

5.1 Hospital staff experiences with mobile robots

In the following, findings upon hospital staffs' experiences with mobile robots are considered in terms of Schatzki's practice theory, unfolding the dynamics between hospital staff and mobile robots. Pinch and Bijker's SCOT is drawn upon to shed light on how the different staff member groups construct mobile robots, while de Graaf is included to discuss human non-use of robots. In addition, levels of collaboration are discussed, along with the impact the mobile robots have on work in hospitals, including a discussion of Suchman and Star. Further, Leavitt is included to shed light on work dynamics. In addition, the roles possessed by hospital staff and mobile robots in HRI in the hospitals are discussed, along with socio-technical considerations and finally, the synergies between political, managerial expectations and real-world implementation of robots, are discussed.

5.1.1 Dynamics between hospital staff and mobile robots

As mobile robots become more prevalent in hospitals, it is crucial to understand the dynamics that unfold between hospital staff and these technological counterparts. To shed light on this intricate relationship, the following section will examine the dynamics between the porter staff and mobile robots at SHS Sønderborg and the medical laboratory technologists (MLTs) and Hubots at OUH by drawing on Schatzki's practice theory, including the four key concepts—practical and general understandings, teleoaffective structures, explicit rules, and material arrangements. By analysing these concepts, insight into the complex interplay between hospital staff and mobile robots can be gained, uncovering the factors that shape their perceptions, behaviours, and collaborative outcomes.

5.1.1.1 SHS Sønderborg

In the following, the dynamics between the porter staff at SHS Sønderborg and the mobile robots, Prop and Berta, will be discussed, as these are characterised as being complex. The following seeks to understand this complexity.

The porters *practical and general understanding* of the robots, referring to their shared knowledge and interpretations regarding the robots' purpose, capabilities, and how they are integrated into their work, derives from their hands-on experience with the robots, including interacting with them when performing daily routines. The practical and general understanding of the robots among the porters is that the robots are frustrating, annoying and hindering their job performance – and the parties co-existence in the hospital basement [179].

The negative perception and behaviours exhibited by the porter staff towards the mobile robots indicate a complex interplay of *teleoaffective structures* within their work environment. The desired outcomes for the porter staff may initially have included efficient workflows in the hospital basement, timely delivery, and smooth coordination between humans and robots. However, their negative perception of the robots suggests that they view the technology as hindering rather than facilitating these outcomes, leading to frustration and resistance. In terms of motivations, the negative emotions displayed by the porter staff, indicate a misalignment between their motivations and the presence of the robots. The fear of job displacement and perceived negative impact on their work efficiency can diminish their motivation to embrace and be constructive about co-existing with the mobile robots. Their motivations might be driven by a desire for job security, maintaining established routines, and performing tasks effectively, which they perceive as being compromised by the robots. The emotional dynamics within the porter staff can significantly influence their perceptions and behaviours towards the robots and result in mocking and sabotaging behaviour, as a way to cope with the perceived challenges and frustrations associated with the robots [179].

The negative perception and behaviours of the porter staff towards the mobile robots can also indicate a possible misalignment with the *explicit rules* governing their behaviour and decision-making. However, there seemed to be no formal regulations or guidelines in place regarding the integration and use of the robots within the porter staff's work environment. Consequently, there were no clear instructions on how the robots were to be utilised and how staff interactions with the technology should be conducted. However, informal guidelines and unwritten rules in the hospital basement were supposed to help shape the behaviour of the porter staff and establish practices to support the acceptance and effective utilisation of the robots, but the negative behaviours and resistance observed among the porters, may be a result of a perceived conflict with these unwritten rules [179].

Considering the material arrangements, the physical infrastructure creates limitations for both porters and mobile robots to navigate. The narrow hallways in the hospital basement creates a constraint in the physical space available for the parties, posing challenges when the robots need to stop to avoid collisions with humans or obstacles. The physical arrangement of the hallways, with insufficient width, makes it difficult for the robots to continue their movement without causing harm, obstruction or stopping. For example, the blocking of passage - when the robots stopped in the hallways due to safety concerns or obstacles, they unintentionally block the passage for both staff and other equipment – creating congestion and disrupting the flow of traffic in the hospital's basement, making it difficult for staff, not least porters on trucks, to move freely. The robots take up a significant amount of space in the already narrow hallways, affecting the hospital staff's ability to perform their tasks efficiently, as they need to navigate around the robots or adjust their pace to match the robots' slow movement. The material arrangement of the hallways and the robots' presence contributes to these blockages and affects the overall efficiency of the hospital staff. The material arrangement of the hallways and the robots' size and speed have a direct impact on the staff's work, leading to frustration, irritation, and a decrease in productivity [179].

5.1.1.2 OUH

Scrutinizing the dynamics between the MLT’s and the Hubots at OUH, the picture is different. From the perspective of practical and general understandings, the collaboration between the mobile robots and the MLTs is characterised by the robots serving as aid for the MLTs. The MLTs emphasise that the mode of delivery for blood samples, whether through robots, human service staff, or pipe systems, is of minor importance compared to the timely receipt of the samples. Instead, their focus is on the purpose, goals, and methods of their tasks within the medical laboratory practice. The MLTs find the Hubots easy to collaborate with and appreciate the robots' straightforwardness and the convenience of using them, as it only requires a few clicks on a smartphone.

The robots' ability to deliver samples faster than human service staff is also acknowledged and valued by the MLTs. This understanding reflects their practical knowledge of streamlining processes and utilising technological aids to improve efficiency. The practical and general understandings of the MLTs shape their perception of the Hubots as valuable assets in their work. In the context of the teleoaffective structures, the combination of teleological and affective aspects shape and guide the actions and interactions between the MLTs and the Hubots. It encompasses the desired outcomes, motivations, and emotional dynamics that influence how the team members, both humans and robots, perform their tasks and collaborate with each other. The MLTs recognise Hubots, as helping hands throughout the day and perceive the robots as valuable for their ability to deliver blood samples. This teleological aspect emphasises the goal of efficiency and productivity within the team. Additionally, the affective dimension of the teleoaffective structures is seen in how the MLTs interact with the Hubots: although the MLTs view the Hubots as tools, they also address them as "he" and "him," indicating a level of personalisation and recognition of the robots as more nuanced than mere objects. This suggests that the MLTs attribute certain emotional characteristics to the robots, considering them as colleagues to some extent. The teleoaffective structures are indirectly influenced by the Technical Manager, as he programmes the robots and define their actions and responses. For example, he programmes the robots to stop when they get too close to a human, which the MLTs interpret as politeness on the part of the robots. However, it's important to note that these actions and responses are not driven by the robots' social intelligence (as they have none) but by their programmed instructions. Overall, the teleoaffective structures shape the collaborative dynamics, motivations, and emotional experiences. The robots' goal-oriented behaviours and their perceived affective qualities contribute to the MLT's understanding and interactions, facilitating their work processes and enhancing their overall effectiveness [179].

At OUH, there is also a set of explicit rules established by the Technical Manager regarding the robots' behavior and operation, including the mantra that the robots must not be irritating or cause disruptions to the hospital staff's routines. Furthermore, he has programmed the robots in terms of where they are supposed to drive and not drive, providing a clear framework for the Hubots to operate in the hospital. These explicit rules help set the tone for collaboration, ensuring that the robots' presence and actions are aligned with the needs and preferences of the staff. The rules create a shared understanding of the robots' role and behavior, fostering trust and confidence among MLTs who rely on the robots' assistance. It is also seen during this study that one of the Hubots breaks the explicit rules and drives into a scooter, causing frustration toward the robot [179].

The physical layout of OUH also plays a significant role in enabling effective collaboration between MLTs and the Hubots. The hospital has wide and open hallways, providing ample space for the robots to navigate without obstructing or impeding the workflow of the staff. This material arrangement reduces the chances of disruptions and allows the robots to move seamlessly within the hospital environment. The design of the hospital's infrastructure, such as the width of the hallways and the placement of furniture, equipment, and other obstacles, is thoughtfully considered to accommodate the presence of robots. The material arrangements allow for smooth and unobtrusive movement of the robots, ensuring that they can perform their tasks efficiently without causing inconvenience or interference with the MLTs' work. However, as mentioned above, one of the Hubots knocks over a scooter one day, which can be considered an example of the material arrangements not being exactly on point. However, the combination of explicit rules and material arrangements in OUH creates a synergistic effect. By integrating explicit rules with suitable material arrangements, OUH optimizes the collaboration between human staff and mobile robots. The rules ensure that the robots' behavior is aligned with the staff's needs and expectations, while the material arrangements provide a physical environment conducive to the robots' operation. This promotes a positive and productive teamwork dynamic, where the MLTs feel supported and the robots seamlessly integrate into their workflow [179].

As seen above, the dynamics between hospital staff and mobile robots are multifaceted and influenced by various factors, ranging from practical understandings and teleoaffective structures to explicit rules and material arrangements. In this examination of the porter staff and mobile robots at SHS Sønderborg and the MLTs and Hubots at OUH, distinct patterns shape the collaboration and acceptance of robots within the hospital environment. At SHS Sønderborg, the porter staff's negative perceptions and behaviours towards the robots reflect a misalignment between their motivations and the presence of the technology. The absence of explicit rules and the challenging material arrangements further complicate their interaction, leading to frustrations and resistance. On the other hand, at OUH, the MLTs' practical and general understandings of the Hubots, coupled with explicit rules and suitable material arrangements, foster a collaborative and efficient relationship [179].
Understanding the dynamics between hospital staff and mobile robots is essential for successful integration and utilisation of robotic technology in hospitals. By recognising the factors that influence staff perceptions and behaviours, hospitals may proactively address challenges, establish clear guidelines, and create supportive material environments to facilitate collaboration between staff and robots.

5.2 Anthropomorphising mobile robots in the hospitals

In the present study, robots in two of the three included hospitals are given names to foster staff's trust and kindness towards them. This practice of assigning human-like qualities or characteristics to robots, in an attempt to create a sense of attachment or emotional connection between humans and machines, is known as anthropomorphism [202]. Anthropomorphising robots helps foster positive interactions between humans and robots, as humans may feel more inclined to treat the robots with care and respect, similar to how they would treat a pet or a person. As robots are gradually being treated as social agents, it is possible that humans are judging robots in a similar way as they would judge other persons [203].

In SHS Sønderborg, the kitchen staff had given names to the robots during a Christmas party. Previous research in HRI has suggested that humans and robots can form emotional attachments to each other, and humans often engage in personalising the robots by ascribing them with names [159]. The names Prop and Berta seem to make a difference for some of the kitchen staff members, creating a sense of attachment and responsibility among them. The staff members who refer to the robots by their given names are also the ones who talk about the robots in a way that shows they take ownership and responsibility for the robotic operations. These staff members appear to care for the robots to some extent. It is interesting to consider Wittgenstein's philosophy regarding the importance of language use in establishing meaning, particularly in relation to how the hospital service staff talk about and experience the mobile robots. According to Wittgenstein, meaning is created through language use in specific contexts. When the porters verbally express that the robots are causing chaos and hindering their work, their use of language shapes a particular meaning about the robots among them. The porters find the robots annoying and perceive them as obstacles that disrupt and delay their work, which is also reflected in their actions and practices [124].

At the next hospital, the robots are not given names but numbers. It is clear that the only person feeling some kind of attachment towards these robots is the technician. Providing the robots with numbers rather than names creates a different language game compared to the first hospital, as the robots remain "just machines" and do not acquire any particular meaning beyond their function. This lack of personal connection or attachment to the robots likely contributes to the staff's lack of investment in the robotic operations.

In the third hospital, OUH, the relationship between the human staff and the robots is completely different. The staff members seem to have a caring and thoughtful relationship with the two robots. They talk in warm terms about them and genuinely feel positive about the robots. The staff members create a particular language game or context in which the robots are more than simply machines but rather seen as helpful and positive contributors to the hospital's operations.

At OUH, the robots have another characteristic human-like feature: a voice. The technical manager vocalises a few sentences to be played when the robot drives in certain parts of the hospital, which can influence the way humans perceive the robots. When driving in the entrance hall, the robots alert their surroundings by playing the sentences "please step aside" and "remember to walk on the right side of the hall." Since a human vocalises the sentences, they are played with a male voice, which often elicits smiles from people nearby. From a postphenomenological perspective, the voice feature of robots at OUH can be considered mediating human experiences. As postphenomenology emphasises the dynamic relationship between humans and technology, considering how the presence of technology shapes human perception, the use of voice on the robots at OUH introduce an additional layer of anthropomorphism. The technical manager intentionally records sentences to be played when the mobile robots are in specific areas of the hospital, demonstrating the intertwining of human intentionality with the design of the technology itself. The specific choice of using a male voice for the played sentences in the entrance hall has an impact on human perception, as it evokes positive responses from people nearby, leading them to smile [160–162,165]. This phenomenon resonates with prior research, such as Clark and Rutter's study (1985), suggesting that visual appearance and vocal behaviour contribute to forming positive impressions of others [204]. The positive reaction to the male voice played by the mobile robots illustrates how the voice feature can influence the affective and social dimensions of human-robot interactions.

Additionally, the voice serves practical purposes as well. In the entrance hall, where the sentences are played out loud, the robots alert individuals to "please step aside" and "remember to walk on the right side of the hall.". These instructions contribute to the robots' role in managing the flow of human traffic within the hospital environment. However, during the fieldwork, an incident occurred where the robot Hubot entered the laboratory without playing its characteristic alerting sound. As a result, the staff did not notice the robot, causing a breakdown in the human-robot interaction. After approximately 10 minutes of waiting, the robot emitted a very loud horn sound, startling the staff and disrupting their work. The unexpected and disruptive nature of the sound led the staff to perceive the robot as "cranky" and even hostile. This example highlights how technological mediation can be unpredictable and subject to errors, and how humans can interpret these consequences in unpredictable ways.

The sentences are only played out loud in the entrance hall, not when the robot interacts with staff in, for example, the laboratory. Instead, the robots play an alerting sound when they arrive in specific places for the staff to notice them. During the fieldwork, Hubot is observed entering the laboratory to deliver samples without playing its characteristic alerting sound. As a result, the staff does not notice the robot, and it stands still and waits for quite a while. After approximately 10 minutes, a very loud horn sound thunders out of the robot and fills the entire room. The staff then starts mumbling about the robot being cranky, asking, "Are we at war?!", "What was that?!", saying "Shhhhhh!!!!" and "Woooow." One person remarks, "That was a FERRY sound!" while another says, "I've NEVER heard him say that before! SHUT. THE. FUCK. UP." The robot that was perceived as a friendly entity is now seen differently. This excerpt highlights how technological mediation can be unpredictable and prone to errors. When Hubot enters the laboratory without playing its characteristic alerting sound, the staff does not notice it, leading to a breakdown in the human-robot interaction. The unexpected and disruptive loud horn sound caused the staff to perceive the robot as "cranky" and even hostile. This demonstrates how technological mediation can have unintended consequences, and humans can interpret these consequences in unpredictable ways. [88] [172].

5.3 Hospital staff–mobile robots relations

According to Verbeek, technology changes human behaviour: both humans and technology are shaped by each other without humans being aware of that. This is supported by Vanessa Evers, stating that robots can be delegated a very limited number of functions compared to humans and will never fully replace humans. But integration of robots in a human life, in the context of the real world, creates a new reality requiring humans to respond to this reality in a new, yet relatively unexplored, way [205][206]. In the following, I will discuss the relations between the hospital staff and the mobile robots.

5.3.1 Building relations between man and machine

To contribute to the understanding of the evolving relationship between humans and robots in various contexts, it is important to contemplate how the robots mediate human experiences and how humans make sense of their relationship with technology. The robots researched in this study, seemed to mediate human experiences by shaping the staff members' interactions with their work environment and technology, and by influencing their perceptions and understanding of their professional roles and relationships. From a postphenomenological perspective, robots mediate human experiences by influencing human perceptions and interactions [88][172]. Human-robot interactions can produce both positive and negative effects on human experiences, highlighting the importance of designing and implementing robots with care.

In the first hospital, SHS, the workers with positive experiences with the robots are limited. There are several situations where the robots cause frustrations, delays, and negativity, which affect the way staff perceive them. However, as the robots are given names, it seems that the tone the kitchen staff has towards them is not harsh but rather tolerant, resigned, and yet helpful, at least for some staff members. They feel compelled to help the robots when they get stuck or encounter errors. Despite the negative experiences, some staff members still show a level of tolerance and even helpfulness towards the robots, suggesting that personalizing the robots, even in the face of negative experiences, can help improve human-robot interactions and strengthen the relations between humans and robots. The insights from SHS illustrate the complex nature of human-robot interactions. Negative experiences with the robots, such as frustration, delays, and negativity, can significantly affect human perceptions of them. However, personalising the robots by giving them names can create a sense of attachment and responsibility towards the robots, which can lead to improved interactions with them. But the perception of robots as mere tools can also have negative consequences, such as dehumanising their role and overlooking their potential capabilities and limitations. Therefore, the perception of robots as tools should be balanced with an understanding of their potential as agents in human-robot interactions. This scenario highlights the need for designers and implementers of robots to consider the role of robots in mediating human experiences and to design interactions that account for the strengths and limitations of both humans and robots. Ultimately, this can help to ensure that human-robot interactions are positive and beneficial for all involved.

Postphenomenologically reflecting on the case of the other hospital I conducted fieldwork in, where the robots had numbers rather than names, suggests a distancing of the staff from the robots. This is supported by the lack of interactions I observed there, the points of contact between workers and robots were very limited. It was merely the technician that interacted with the robots, as he was responsible for their daily running, including monitoring their ways. This distancing between kitchen staff and the mobile robots in this given hospital, seemed to lead to a lack of attachment and responsibility towards the robots – and to a lack of relationship between the staff and the robots. This suggests a lack of understanding of the robots' potential capabilities and limitations, which may cause failure in fully utilising the technology, potentially leading to missed opportunities for increased efficiency and effectiveness in work processes. Overall, the lack of relationship between staff and robots in the second hospital illustrates the importance of considering the ways in which human-robot interactions are mediated by personalisation choices, such as the use of names or numbers. These choices can significantly impact the ways in which staff perceive and interact with the technology, ultimately affecting the effectiveness and efficiency of its use. Therefore, it is important to design interactions that consider the potential for human-robot relationships and to implement the technology in ways that foster positive human-robot interactions [44][88]. Positive relations between humans and robots are – on the contrary – seen in the third hospital, OUH, where it seems that part of the staff members have a wacky and funny relationship with the robots. One staff member, in particular, has a special bond with the big robot, Hubot. Despite being told by the hygiene nurses not to, he decorates the robot. According to him, Hubot enjoys Christmas decorations, and he finds it cozy and "something extra." He has a close connection with the robot, personalises it, and takes care of it. He knows the sounds it will play and shares anecdotes of his experiences with this particular robot. He also expresses that Hubot is polite and never intentionally behaves in a way that causes negativity for him or his human colleagues. The staff members refer to the robots as male and talk to them as if they were persons. When discussing robotic errors, they do not use technical terms but express that there are things the robots do not understand. For example, one of them states, "When we have to enter the code, MiniHubot doesn't always understand that.". The general attitude towards the robots at OUH, among the staff using them, is that the technology has improved workflows, but understanding the robots is not always easy. It appears that the staff's fondness for the robots increases when they engage in "funny" interactions with them [44]. Other workers express varied perspectives on their collaboration with the robots, describing the technology as a tool, "just a robot," a supportive system that also requires support itself, a valuable aid in their work routines, a source of relief, and even a colleague, or at least something akin to a colleague. These perspectives can overlap and contribute to our understanding of the workers' experiences in working alongside the robots. As mentioned previously, initial impressions can differ from how they may evolve over time. Human perspectives on robots have the potential to change over time, as evidenced by the research of Ljungblad and colleagues, who observed that hospital staff's perceptions of transport robots transformed from viewing them as "something alien" to considering them as "work partners" as the robots became more familiar to the workers [154].

Contemplating the varying human perspectives on the robots, the multistability, through the postphenomenological human-technology relations lens, it is possible to gain insights into how these robots mediate human experiences [89]. These perspectives highlight the robots' role in shaping how the staff members perceive and approach their work, and how the staff members understand their relationships with technology in the context of their professional roles. The robots mediate workers' experiences by shaping how the staff perceive, interact, and understand the world around them. The staff members at OUH interact with the robots as if they were persons, referring to them by name, ascribing them gender, and personalising them through decorating, language and anecdotes. The robots have become part of the staff's social and professional lives in the workplace, and their interactions with the robots affect their perceptions of their work environment and workflow. This highlights the importance of understanding the role of technology in shaping human experiences. The staff members' interactions with the robots influences their perceptions of their work environment and workflow, and their understanding of their professional roles and relationships. This suggests that technology can shape human experiences in ways that are not always immediately obvious, and that a deeper understanding of these dynamics is necessary for effective human-robot interactions. The robots seems to mediate human experiences by shaping the staff members' interactions with their work environment and technology, and by influencing their perceptions and understanding of their professional roles and relationships. The varying perspectives demonstrate that the relationship between humans and robots is not one-dimensional and straightforward. Rather, they highlight the complexity of human-robot relationships and the need for a nuanced understanding of these. In addition, the examples demonstrate how human-robot relationships can be more positive and productive when humans perceive the robots as social actors rather than simply as machines and highlights the importance of personalisation and socialisation in human-robot interactions.

5.3.2 Types of hospital staff-mobile robot relations

Considering Ihde's and Verbeek's types of relations in terms of the hospitals included in this study, it is clear that there are various types present at the three sites [88] [172].

First, the embodiment relations are evident as some hospital staff members (in SHS) currently utilize the robots to transport carts over certain distances, where the robots function as an extension of themselves. Some staff members currently consider the robots as an extension of their own capabilities, particularly when the robots are functioning properly. Furthermore, hospital staff members currently personalize the robots by giving them names, suggesting a sense of attachment and merging with the robots as extensions of their responsibilities. Additionally, the hermeneutic relation is present as staff members currently interpret and understand how the robots represent the world, based on their experiences with frustrations, delays, and negativity, but also joy, fun, efficiency, and relief caused by the mobile robots. By observing and interacting with the mobile robots, staff members currently develop a sense of interpretation and understanding of the robots' behavior and their impact on their work routines. This relation highlights the staff members' current engagement in making sense of the robots' actions and their interpretation of the robots' role in their daily tasks.

The alterity relation is present as well, at the hospitals, specifically in instances where the robots are intentionally turned off by the hospital porters to minimise elevator traffic and allow the porters to carry out their duties without delays. This intentional alteration of the robots' functioning contributes to the perception among staff members that the robots are not functioning properly. In addition, the staff members interact with the robots as they carry out their responsibilities in the hospital setting, while the world, represented by the hospital environments and the staff members' tasks, remains in the background while the staff members engage with the robots. However, occasionally the environment interfered with the robots' performances at both SHS and OUH. In spite hereof, the hospital environment and the tasks performed by the staff members continue to exist and operate independently of the robots – and staff members have their established roles and responsibilities within the hospital setting, which the presence of the robots does not fundamentally change. While the staff members engage with the robots and interact with them in the course of their work, the robots at SHS are considered separate entities from the staff members and the existing world they operate in, and the mobile robots are seen as tools or aids in fulfilling certain tasks. At SHS, the robots are perceived as external entities, operating alongside the staff members within the established hospital environment, while the staff members maintain their sense of identity and responsibility within their roles, along with recognising and interacting with the robots as distinct entities. On the contrary, at OUH, the mobile robots are considered an integrated part of the staff [88][172].

The deployment of robots in the hospital setting currently disrupts the existing background - or context - in which the staff members currently perform their work. At SHS, the background relation is evident in the disruptions and delays caused by the robots' presence: the standing robots currently obstruct passages in hallways, resulting in disruptions to staff members' work routines and affecting the efficiency of operations. The robots currently take up space in the hospital basement with their attached carts, causing inconveniences and disruptions to the daily routines of the already busy staff members. This change in the physical layout of the hospital and the additional equipment brought by the robots currently alters the background of the work environment. Moreover, the robots also currently lead to changes in work procedures, both in SHS and OUH. The staff members at SHS currently need to adapt their routines to accommodate the presence of robots and collaborate with them effectively, creating a new background against which the staff members currently operate. Thus, the background relation at SHS currently signifies the changes that occur in the work environment, both physically and in terms of routines and procedures, due to the introduction of robots. The robots' presence currently disrupts the existing background and necessitates adjustments in the way the staff members currently carry out their work. At OUH, the robots do not currently disrupt or interfere; rather, they currently relieve staff from walking around the hospital with samples.

Another relation present at the hospitals is the cyborg relation, suggesting a merging of human and machine elements. Some of the staff members at SHS and OUH go beyond perceiving the robots as mere machines and forms a connection with them, by giving them names. By personalising the robots in such, the staff members attribute a sense of identity and individuality to these machines, implying a merging of human and technological aspects, blurring the boundaries between the human and machine elements. The robots become more than just tools or equipment; they become integrated into the staff members' roles and responsibilities. This merging of human and machine elements is a characteristic of the cyborg relation. It highlights the transformative nature of the robots, as they go beyond their physical presence and become intertwined with the staff members' work processes and identities. In addition, the immersion relation is also present at the hospitals. It refers to the ability of the robots to respond and interact with humans in a way that creates a sense of immersion or engagement – the robots' ability to respond to the staff members' actions and commands. At SHS for example, the hospital service staff members interact with the robots through a tablet, on which they give the robots instructions, expecting them to perform certain tasks. The robots, in turn, respond to these interactions by carrying out the requested actions. Another example is the robots and staff reacting when they approach each other in the hallways or when staff members decorate a robot for Christmas. This interactive process between hospital staff members and the mobile robots creates a sense of immersion. The immersion relation should allow for a more seamless integration of the robots into the work environment, which is clear at OUH, and more complex at SHS, as staff members can not rely on the robots [88] [172].

There is a variety of lenses one can discuss the findings from this study through. When looking at the findings from the three hospital through the lens of human-technology relations, it is natural to distinguish between three approaches for understanding the general relationship between the service staff and the mobile robots: extension, dialectics and hybridity.

The first hospital serves as an example of the extensionist approach, as the kitchen staff currently give the robots names and currently view them as an extension of their own responsibilities. They currently feel a sense of attachment to the robots, and their language currently suggests that they currently take responsibility for the robots' operations. This perspective currently sees technologies as an extension of human agency and intent. On the other hand, the robots at the second hospital are currently only given numbers, indicating a more alienated relationship between humans and technology. The kitchen staff do not appear to have any emotional connection to the robots and are currently not invested in their operations. This perspective aligns with the dialectical approach, in which the robots are currently seen as opposing forces that overpower human intentions and create a sense of alienation between humans and the products they produce. In contrast, the staff members in the last hospital have a more thoughtful and caring relationship with the robots. They talk about the robots in a positive manner and express genuine optimism about them. This perspective aligns with the hybridity approach, in which human-technology relationships are seen as complex and mutually shaping. Both humans and technologies influence and change each other in various ways, creating a symbiotic relationship. In this context, the staff members currently see the robots as partners in their work, and they work together in a collaborative manner, creating a more positive and productive work environment. These insights contribute to our understanding of the evolving relationship between humans and robots by highlighting the complexity and nuance of these relationships, the importance of personalisation and socialisation in human-robot interactions, and the role of technology in shaping human experiences [88][172].

5.3.3 Breaking down relations between man and machine

The relations between humans and robots are influenced by the type of interaction and collaboration among them. As seen at SHS Sønderborg, porter staff who do not benefit from robots being installed at the hospital, seems frustrated and irritated about them, while kitchen staff, who are benefitting from the robots, perceives them a great support, when they operate without delays and errors. Unfortunately, the robots are delayed or affected by errors quite often, leading

to frustrations among the kitchen staff. However, these frustrations are bound to the behaviour of the porters, as it is often their actions that causes the robots to fail.
I am told "war stories" from the hospital kitchen staff, of how porter staff sabotage robots, hindering them in performing tasks. The sabotage is done on purpose, where porters kick the robots, pour food into them, and even urinate in them. As noted by Ovarec, sabotage, attacks, and what she calls "anti-robot attacks" on robots, can be characterized as a new form of human violence. There are a variety of types of attacks on robots by humans and the type may vary depending on how the human perceives the robot and from where the human's rage against the robot is rooted [207]. According to Sorenson, robot sabotage is often performed as an act of resistance, typically manifested through three different types of resistance: non-use, misuse and sabotage. She defines non-use as “the abandonment or gradual disuse of a newly implemented technology”, misuse as “the interference with a robot or robotic system that prevents it from fulfilling its intended tasks" and sabotage as “deliberate damage to a robot or a robotic system with the intent to render it useless”.
In present case, both non-use (staff members choosing not to use/collaborate with the robots), misuse (staff members interfering with the robots, for example by turning the systems off) and sabotage (staff members pouring stuff into the robots) are evident [208].

When a human attacks a robot, it may not necessarily indicate a deliberate and calculated action, but rather an immediate and reflexive response. Nevertheless, such attacks can also stem from a range of negative emotions and motivations, including strong personal biases and connections to broader concerns and assumptions about automation and economic hardships [209]. Hate, which is a multifaceted emotion, can be comprised of various negative emotions such as resentment and disapproval [205]. A widespread type of abuse is dysfunctional contact with unaggressive robots, rooting in misinformed humans or inappropriate use of robots. In the western countries, this type is sabotage is widespread, in the work of Ovarec is used an example from a South African context, asserting “We burn our robots in Africa; they keep trying to steal our jobs.” [207]. In the hospitals in Denmark, the most common type of sabotage is kicking of robots and according to related works unfolded in Ovarec’s work, this kind of sabotage occurs often for mobile (food) delivery robots. Some attacks are aimed at injuring the robots, similar to an attack on another human being, while others are intended to cause damage to the organisation by requiring repairs or replacements of the robot. Robot attacks can be seen as a social practice that allows individuals to express their attitudes towards automation and societal changes. This may root in the widespread ontology of ’man vs machine’; human against robot. The contrast between humans and robots is a common theme in many societies, appearing in science fiction, news, and economic reports. This leads to the formation of anti-robot sentiments in various messages and information shared on social media. Consequently, people have learned about robots in particular ways and may have contributed to the misconception, that automation will result in a significant loss of jobs.

Resistance to technological progress and the intentional destruction of machinery is not a new phenomenon, attacks on technological entities have a long history. Almost 80 years ago, Stern observed the resistance to technological advancements and identified the actions of "machine wreckers" who expressed dissatisfaction by deliberately damaging machinery [211]. Although these individuals had limited options for their attacks, they were strategic in their actions and timed them to create the greatest impact [207]. During the years 1815-1848, the Luddites, who were skilled workers, also engaged in aggressive activities to counter specific technological changes [207]. Their actions caught the attention of political and social leaders who became aware of the issues they were protesting. An example of Luddite sabotage was the destruction of stocking frames, which were machines used in the textile industry to produce stockings. The Luddites saw the use of these machines as a threat to their livelihoods, as they believed that the machines would put them out of work. As a result, they organised and attacked factories where the machines were used, often breaking into the factories and destroying the stocking frames. This sabotage was seen as a form of resistance against the use of machines in the textile industry and a way for the Luddites to protect their jobs. The term "Luddite" is often used in reference to such perspectives [207] [211].

Understanding the historical and contemporary resistance to technological progress can help inform the development of policies and practices that balance the benefits and risks of autonomous technologies. Not least in hospitals, it is important to critically examine the narratives surrounding autonomous machines, in order to develop a more nuanced understanding of the issues at stake. The points of views ought to be nuanced, rather than black/white, rooting in dystopian science fiction.

5.3.4 Environmental influences on staff-robot collaboration

One of the primary findings of this study pertains to the significance of the environment in facilitating successful human-robot collaboration, as the research sheds light on how the design and characteristics of the shared space influences the performance and effectiveness of robots within the hospital settings. The following section discusses the impact of the environment on the robots' ability to carry out their tasks, contemplating the findings through Don Ihde's human-technology-world relations and emphasises the importance of deploying robots in environments that align with their operational requirements [88].

The study findings reveals that the environment in which the robots are deployed plays a crucial role in their ability to execute tasks effectively. At OUH, the robots are implemented in areas of the hospital that are well-suited for mobile robotic operations. Conversely, the research identified that the environment at SHS poses challenges to the robots’ performances. The research shows that the success of human-robot collaboration heavily rely on the alignment between the robots' operational requirements and the environment in which they are deployed and underscore the significance of an environment that is tailored to meet the operational needs of robots, when fostering successful human-robot collaboration.

Contemplating this from Don Ihde's framework of human-technology-world relations, valuable insights can be gained, when examining the impact of the environment on human-robot collaboration within the hospital setting. The environment shared by mobile robots and hospital staff can be seen as a technological mediation that shapes their collaborative dynamics. Highlighting the importance of a well-suited environment for successful human-robot collaboration, resonates with Ihde's framework, as the design and characteristics of the environment, including factors such as hallway width and traffic flow, act as mediators between humans, robots, and the tasks they perform. The environment shapes the possibilities and constraints of interaction and influences the roles and behaviours adopted by humans and robots. The environment at OUH functions as a transparent mediator, facilitating efficient human-robot collaboration by minimising frictions and disruptions, as it is aligned with the operational requirements of robots, allowing for seamless integration and smooth task execution. In addition, the broad hallways and absence of heavy traffic enable the robots to navigate freely, minimising obstacles and interruptions. Conversely, in areas such as the narrow hallways of the basement, the environment becomes a mediating factor that constrains the capabilities of the robots and influences human behaviour. The limited space and presence of various types of traffic at SHS, impede the robots' movement and compromise their ability to perform tasks effectively. The environment becomes a noticeable mediator, shaping the behaviour and expectations of both humans and robots. Ihde's framework serves as a reminder that technologies, including robots, do not exist in isolation but are part of a larger sociotechnical context. The environment, as a technological mediator, influences the expectations, interactions, and practices of both humans and robots. In this study, the environment influences the human expectations of the robots, as the hospital staff anticipates a seamless integration of robots into their real-world work environment. The discrepancy between these expectations and the actual performance of the robots at SHS, highlights the significance of considering the environment as a key factor in shaping human-robot collaboration, as it is done at OUH [88].

By incorporating Ihde's perspective, understanding of the intricate relationship between humans, robots, and the environment, can be deepened. The study's findings suggest that successful human-robot collaboration requires careful consideration of the environment as a technological mediator that shapes the possibilities and limitations of interaction. Recognising the importance of aligning the environment with the operational requirements of robots allows for a more nuanced approach to deploying robots in real-world settings. Don Ihde's framework of human-technology-world relations provides a valuable lens for analysing the impact of the environment on human-robot collaboration, as acknowledging the role of the environment as a technological mediator, can allow for gaining insights into how the characteristics of the shared space influence the dynamics and effectiveness of collaboration [88].

5.4 Hospital staff's social construction of mobile robots

Another perspective, another lens to scrutinize the robots in hospitals through, is Social Construction of Technology (SCOT). SCOT delves into how distinct social groups have utilised or are currently utilising a particular technology. In the context of hospitals, the perception of robots varies among different service staff groups, resulting in diverse perspectives on the same technology. These differing viewpoints influence the collaborations and interactions between various human service staff members and the mobile robots.

Scrutinising the social construction of the mobile robots in the hospitals included in this study, firstly relevant social groups are defined as illustrated in the figure below. Across the hospitals, there are different groups of users and non-users. The users are respectively kitchen staff, MLTs, Technical Manager and Technician, while the other social groups are non-users [175].

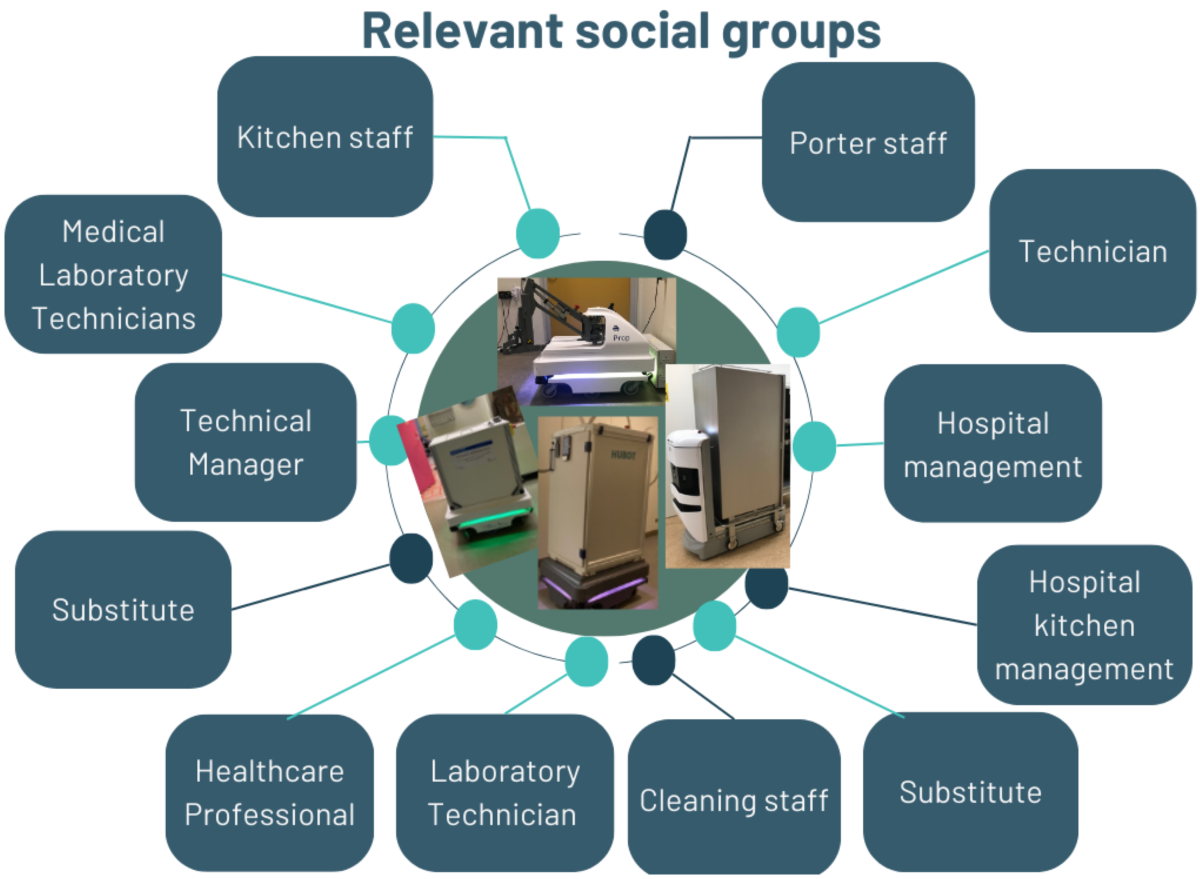


Figure 48 Robots and relevant social groups in the three hospitals in a SCOT perspective

The social groups have different perceptions of the robots. At SHS Sønderborg, the kitchen staff uses and interacts with the robots for tasks such as transporting carts and they perceive the robots as helpful, amusing, personalising them, not least by using the names, Prop and Berta. The kitchen staff members have a distinct perception of the robots, seeing them as more than just tools or co-workers. To them, the robots are not merely machines, but rather individuals known as "Prop and Berta" . However, some of the kitchen staff members expresses frustrations towards the robots, when they are not functioning reliably. Consequently, these staff members refuse to use the robots. At SHS Aabenraa, the users are also kitchen staff and the Technician. The kitchen staff perceives the robots as great support when they are driving without delays, however, the delays occours often, resulting in the hospital staff losing trust in the

robots. Furter, they experience that the robots are often standing still which they interpret as errors.
Neither do the technician fully trust the robots.

At OUH, the users are respectively the MLTs and the Technical Manager. The TM makes sure that the robots are not causing frustrations and annoyance and it seems, consequently, that both users and non-users are pleased with the mobile robots. The MLTs interpret the robots as reliable, due to the robot responsibility taken by the Technical Manager. The MLT's perceive the robots as efficient and yet cosy and fun, which for example becomes evident when they decorate one of the robots for Christmas. The other robot is not decorated, because they do not know if the robot would like decorations. This anthropomorphisation and the consequences hereof, bears witness to a caring, informal view upon the robots, from the MLTs point of view. In contrast, the Technical Manager thinks that the MLTs ought to treat the robots as something formal, serious and sober, not least considering the important task the mobile robots carry out, in a setting where life and death is part of the everyday.
At SHS Sønderborg, the porter staff tend to perceive the robots as disrupting and slowing down their work, finding the mobile robots annoying and inefficient, while mocking and sabotaging them.
The non-users at SHS Sønderborg have varying perspectives upon the mobile robots. The healthcare professional included in this study has a neutral perception of the robot, while a laboratory technician explicate that she found the robots to be something special and funny. The hospital management perceive the robots as a very efficient technology that can effortlessly automate part of the hospital logistics and increase efficiency, reduce costs and relieve staff. This perception is shared by the kitchen management. Finally, a substitute from the kitchen staff member staff seems to have had a positive perception of the robots, finding joy and entertainment in their presence. He even develops a narrative around their interactions, based on an anthropomorphic view of the robots, adding a playful and enjoyable element to the HRC, creating a fun atmosphere.

These varying perspectives upon the mobile robots can be characterised as the interpretive flexibility, witnessing how social groups attribute different meanings to the same artifact, regardless of functionality, user-friendliness, size, aesthetics, etc. A technological artifact can always be interpreted differently depending on the context in which it is used, leading to conflicting influences and rising disagreements, discussions, and controversies. In addition, different interpretations of the robots' role and impact, lead to varied attitudes and actions by the social groups involved [175].
In this case, the mobile robots leads to conflicts between the kitchen staff and the porter staff, as the porters' job performances are affected by the robots in the basement; robots that are to relieve the kitchen staff; kitchen staff have gotten a new type of informal task in the realm of this, namely robotic caretakers, looking out for the robots, preventing and troubleshooting errors and sabotage from porters, whose negative perceptions drive their sabotage attempts, hindering the robots' functionality and creating further tensions.

According to SCOT, the gradual stabilisation will drain controversies over time, allowing for closure, either rhetorically or by redefining the problems [175]. In the case of SHS Sønderborg, rhetorical closure is attempted by the kitchen management, trying to convince the porters to treat the robots with respect by anthropomorphisation:

"[...] some of our porters [...] they speak rudely to and about us and the robots, something like "You damn well just...". And then I usually say, 'Listen, we speak nicely to you, would you also speak nicely to Berta? She can actually get upset.'" [unpublished]

According to SCOT, technologies are entangled with social groups' influence, knowledge, experiences, as well as societal history and development, and consequently, the design of a technological artifact often emerges from events and controversies that have influenced the technology in different directions [175]. In this case, the robots are equipped with controllers/joysticks allowing users to move the robots manually, in case of robotic errors. This is based on experiences with robots stopping in front of emergency elevators in the hospital, causing dangerous situations. By considering the SCOT perspective, it becomes evident that the perceptions and actions of different social groups significantly impact the implementation and acceptance of hospital service robots.

5.5 Human non-use of robots

This section focuses on human non-use of robots through two primary themes: the robots' role as catalysts for change and their perceived ineffectiveness. The first theme examines the alterations in work procedures and routines that result from the robots' deployment, while the second theme explores the obstacles encountered due to the robots' inability to adjust to the hospital surroundings. The section argues that robots are not just mere machines; they act as agents of transformation, necessitating a more comprehensive approach to their implementation. The section focuses on the non-use experienced at the SHS hospitals, as I do not experience non-use at OUH, presumably as the robots at OUH are used all day and widely accepted by staff.

The research findings unveil distinct usage patterns of robots among different age groups within the staff at SHS. Elderly staff members display a higher inclination towards utilising the robots, specifically Prop and Berta, in their work processes. In contrast, younger staff members often choose to bypass the use of these robots due to the multitude of issues they encounter. While the robots prove beneficial for older staff members, particularly in assisting with the movement of heavy carts, their reliability and potential to cause work delays are concerns. Some staff members, particularly the younger cohort, choose to retrieve carts themselves instead of relying on the robots. Furthermore, instances of tampering by individuals occasionally result in robot malfunction.

Among those assigned to share tasks with the robots, some individuals chose to perform the tasks independently due to the robots' unreliability. This observation underscores the inherent conflict in balancing work pace in human-robot collaboration, as robots' errors and setbacks directly impact work efficiency. Recognising the significance of harmonising work tempo in human-robot cooperation is crucial, as non-users perceive the robots as impeding their workflow. Furthermore, the non-users state that they can work faster themselves and do not consider the heavy pulling/pushing to be a problem; rather, the robots can be a source of frustration due to errors that influence the work hours. Despite the potential benefits of robots in the workplace, such as increased efficiency and productivity, some of the workers are reluctant to rely on them. One of the biggest issues is the many procedures involved in the work that are invisible, making it difficult for the robots to interact effectively with the dynamic work environment. This creates a need for a more holistic approach to their deployment, as the managers' expectations for robots to simply automate work tasks and procedures are unrealistic in practice.

When contemplating the phenomenon of human non-use of robots in a hospital setting, as seen at SHS, it is natural to draw upon insights from De Graaf to shed light on the underlying reasons for non-use. De Graaf emphasises the importance of adopting a user-centric approach to technology acceptance and acknowledges that users play a significant role in shaping the acceptance and non-use of technology, necessitating an understanding of their perceptions, preferences, and behaviours. At SHS, there seems to be distinct attitudes toward robot usage among different age groups: elder staff members are more inclined to use the robots, primarily due to specific needs, such as difficulty in moving heavy carts. However, younger staff members encounter numerous problems with the robots, leading them to skip usage. This aligns with the user-centric approach advocated by De Graaf, emphasising the significance of understanding users' perspectives and experiences [212].

Furthermore, the findings uncover several other factors contributing to the non-use of robots. The perceived ineffectiveness of robots and their unreliability emerge as prominent reasons for staff members' reluctance to rely on them – and delays in the work process and the occurrence of errors that impact work hours have led to frustration among users. At SHS, there are conflicts in balancing the work tempi between humans and robots, as some staff members feel that the robots slow down their work. This underscores the intricate nature of collaboration between humans and robots, where multifaceted interactions come into play and calls for a holistic approach to the deployment of robots in a setting as hospitals. Thus, recognising the robots' roles as agents of transformation and change. The implementation of robots in the hospital brought about alterations in work procedures and routines, leading to disruption and conflicts among staff members. Hence, I argue for a comprehensive understanding of robot deployment that goes beyond technical functionality, to encompass broader ecological terms, aligning with De Graaf, who emphasises the need to view robots as requiring assistance and support for effective collaboration between humans and robots [212].

In addition, De Graaf also emphasises the value of insights from non-users in informing the design and development of technologies [212]. In present case, it is revealed that mobile service robots in the hospital SHS were not considered reliable enough for critical tasks, such as transporting blood samples or medicine, and they disrupted the daily routines of staff members. On the contrary, at OUH, the robots’ primary task was to transport blood samples, and the workers did not doubt that the robots would do so, with or without assistance from the Technical Manager. This highlights the importance of addressing issues such as robot support, reliability, adaptability, personalisation, and space considerations, when deploying robots in the wild, to ensure usage.

Scrutinizing human non-use of robots in the hospital setting through the perspective outlined by De Graaf, valuable insights into the underlying reasons for non-use can be obtained. The user-centric approach, understanding of sustained engagement and adaptation, consideration of social and organisational contexts, and incorporation of non-users' perspectives all contribute to a comprehensive understanding of the complexities surrounding human-robot interactions. By leveraging these insights, future developments in robot technology can be more effectively tailored to meet the needs and expectations of users, leading to enhanced acceptance and utilisation in real-world settings, such as hospitals.

5.6 Levels of collaboration in SHS and OUH

Based on the findings of this study, the robots at SHS and OUH, seems to exhibit different forms of interaction with human staff. In SHS, staff members spend a significant amount of time assisting the robots, and it seems the interaction between humans and robots is more akin to human-robot cooperation or coexistence than collaboration [138–140]. The staff members are required to assist and support the robots, indicating a level of dependency on human intervention, suggesting that the robots are not fully capable of independently performing their tasks and required ongoing human involvement to operate effectively. Therefore, it can be inferred that the level of collaboration in SHS is limited.

In OUH, the clear division of tasks and the responsibility placed on the Technical Manager (TM) for troubleshooting and support, suggest a higher potential for human-robot collaboration. At OUH, there are two main teams involved: Team HTM (consisting of Hubots and the Technical Manager) and Team HMLT (consisting of Hubots and the Medical Laboratory Technologists). Each team exhibits a different form of interaction and relationship between humans and robots, which can be characterised as follows:

1. Team HTM (Hubots and the Technical Manager)
    a. Paternalistic dynamic: The Technical Manager (TM) assumes the role of caretaker for the robots and possesses extensive knowledge and understanding of their functioning.
    b. The TM has been involved with the robots from their early stages of development and has actively built, programmed and refined them, to adapt to the hospital environment and the needs of the humans they interact with.

c. The TM actively monitors the robots using various tools and devices, ensuring real-time oversight and quick response to any errors or malfunctions.
d. The TM emphasises the importance of the robots being non-irritating to maintain goodwill among the hospital staff and prevent negative perceptions.
e. The TM's dedicated presence and prompt troubleshooting contribute to minimal downtime for the robots.
f. The TM's approach to the robots is characterised by a neutral and objective bond, addressing them as "they" and "it."

2. Team HMLT (Hubots and the Medical Laboratory Technologists)
    a. The robots, known as Hubots, play a supportive role in the daily activities of the Medical Laboratory Technologists (MLTs).
    b. The MLTs perceive the Hubots as tools or supporting tools that aid them in their tasks, particularly in the delivery of blood samples.
    c. The Hubots are considered convenient to use, as they require minimal effort from the MLTs, who can easily interact with them through smartphone controls.
    d. Some MLTs demonstrate a personalisation of the robots, referring to them using male pronouns and considering them as colleagues to some extent.
    e. The MLTs appreciate the Hubots' ability to handle repetitive or burdensome tasks, relieving them from such responsibilities.
    f. Challenges arise in relation to the shared use of elevators, as the robots' movements can slow down the MLTs' work, causing minor disruptions.

In terms of classification, the collaboration between humans and robots in both Team HTM and Team HMLT can be considered a form of human-robot collaboration. Collaboration implies a joint effort and active involvement of both humans and robots to achieve common goals. In Team HTM, the TM collaborates with the robots to ensure their smooth functioning and address any issues that arise. In Team HMLT, the Hubots collaborate with the MLTs by providing support and assistance in their tasks. While there are elements of cooperation and coexistence present, the predominant characteristic is collaboration. Cooperation implies working together in a coordinated manner, but it may not necessarily involve a close and interactive relationship. Coexistence, on the other hand, suggests a peaceful coexistence between humans and robots without direct interaction or shared goals. Both Team HTM and Team HMLT demonstrate active cooperation, shared goals, and mutual support between humans and robots to enhance efficiency and task performance in the hospital setting, reflecting a form of human-robot collaboration [138–140].

5.7 The impact robots have on work: tasks and organisational view

The aim of robots in the workplace, in the included hospitals, is to enhance the productivity and well-being of workers, rather than to replace them. The clear and straightforward division of tasks assigned to the robots at OUH eliminates the need for staff members, specifically the

MLT's, to coordinate or delegate tasks. The MLT's are relieved from the burden of troubleshooting or managing the robots, instead the TM tells and teaches the staff what to expect from the robots and what to expect from him, as he is designated as the point person for robot-related matters. This distinct accountability is well-known among staff members, ensuring a streamlined process for addressing any errors or malfunctions. Consequently, troubleshooting at OUH is a straightforward process, facilitating smooth collaboration between the staff and the robots. Thus, the robots at OUH are fulfilling the aim with which they are deployed.
In contrast, SHS struggles with the everyday operations of robots in their routines. As the responsibility for the robots is not clearly assigned to anyone, it leads to a lack of ownership, resulting in a situation where every staff member is responsible for the robots, including troubleshooting, despite the absence of proper training. Consequently, errors and malfunctions occur frequently, requiring significant time and effort from the kitchen staff to assist the robots in carrying out their tasks. Thus, the robots at SHS are not fulfilling the aim with which they are deployed. The presence of the robots in SHS create a perception among the staff that they are complicated and time-consuming sources of additional work, rather than helpful aids in their tasks. Some members of the kitchen staff even refuse to work with the robots, opting to undertake the extra workload themselves. Others who collaborate with the robots feel the need to closely monitor their performance, following them during task completion to ensure accuracy. This increases the workload for the staff and decrease overall efficiency in the kitchen operations. In contrast, at OUH, the MLTs collaborating with the robots regards them as valuable assistants in their work processes. The robots seamlessly integrate into their workflow, often going unnoticed due to their unobtrusiveness and lack of disruption. The MLTs are not burdened with the responsibility of assisting the robots or rectifying errors, allowing them to focus on their core tasks. They have confidence in the robots' ability to successfully execute assigned tasks and relied on the TM to address any issues that arose. The presence of the TM as a dedicated resource acted as a safety net for the MLTs, ensuring a smooth collaboration between the staff and the robots.

The disparity in the perception and effectiveness of robot integration between the two hospitals highlights the importance of clear task allocation, dedicated responsibility, and a supportive framework for successful collaboration between humans and robots. OUH's streamlined approach, where the TM assumes the primary responsibility for the robots, contribute to a favourable working environment, whereas SHS's lack of clear ownership and the resulting burden on the kitchen staff, hinders the smooth functioning of the robotic system.

5.7.1 Exploring plans and situated actions in HRC at the hospitals

Drawing on the perspectives of Plans and Situated Action, it is in the following discussed how the mobile robots impact the work tasks and routines of the hospital staff, and the intricate interplay between plans and situated actions. Furthermore, this section delves into the application of Articulation Work as a lens for understanding and analysing the collaborative efforts and interactions between hospital staff and mobile robots and finally, the Leavitt diamond model is used to shed light on robots' organisational impact [201].

Staff members from SHS Sønderborg and SHS Aabenraa explain that the mobile robots are disturbing their working routines when they are standing still and *do not work*, hence staff will have to wait for the robots, causing frustrations and delays to their work. Contemplating this from the perspective presented in Plans and Situated Action illustrates the impact of the robots on the working routines of the kitchen staff and the challenges that arise, when plans and situated actions do not align. The example emphasises the need to bridge the gap between plans and situated actions to ensure successful collaboration between humans and robots. The frustrations experienced by the kitchen staff when the robots stand still or encounter delays highlight the limitations of relying solely on preconceived plans. This disruption in the kitchen's routines not only creates additional burden but also undermines the efficiency and effectiveness of the staff's overall operations. The staff's low hopes and aspirations regarding the robots stem from their repeated experiences of the robots being interfered with or turned off. They have become accustomed to the robots not functioning as planned, leading to a loss of trust in their reliability. The staff has to adapt to the robots' unreliability, resulting in a decreased willingness to rely on them and a preference for taking on logistics tasks themselves to ensure timely completion. This highlights the tension between planned actions and situated actions in the collaboration between the kitchen staff and the robots. The staff's reliance on plans and their frustrations with the robots' delays demonstrate the challenges that arise when the robots' performance does not align with the expectations set by the planned actions. The staff's situated actions of taking on additional tasks, reflect their ability to adapt to the context and meet their work requirements in response to the robots' limitations.
To address these challenges in the future, it is crucial to consider the situated context and incorporate it into the planning and design of robots, their functioning and implementation. Understanding the complex and dynamic nature of the hospital environment is essential for developing robots that can effectively support the staff's everyday working routines. This requires improving the robots' reliability, responsiveness, and coordination to minimise delays and build trust with the staff [185].

Incorporating the principles of situated action allows for the development of robots that go beyond following predefined plans. Such robots will be able to perceive their surroundings, anticipate obstacles, and adjust their actions accordingly. Robots should be equipped with the ability to seek input from staff, aid when needed, and establish open channels of communication and feedback. Furthermore, fostering a collaborative relationship between staff and robots, comprises actively involving the staff in the development process, as their expertise and insights are invaluable for improving the performance and usability of robotic systems. By creating opportunities for staff to express concerns, share their knowledge, and contribute to decision-making, the design of robots may better meet the specific needs of the users.
Ultimately, the goal should be to design robots that not only optimise efficiency – and actually does so - but also enhance the overall well-being and satisfaction of the staff. Plans should be

seen as tools for orientation rather than comprehensive representations of the work context. Considering the broader environment, social dynamics, and user needs allows for a more holistic approach to technology design [185].

5.7.2 Exploring articulation work in HRC at the hospitals

This section focuses on the dynamics between the hospital staff and the mobile robots, exploring the application of articulation work as a lens for understanding how robots affect work. Applying articulation work as a lens for discussion, the collaborative efforts and coordination mechanisms involved in facilitating interaction and collaboration between humans and robots, are in focus. These involves the negotiation of meaning, understanding, roles, responsibilities, and actions between humans and robots to accomplish shared goals, as well as the establishment of mutual understanding and effective collaboration [190,192,193].

The completion of tasks for hospital staff and robots involve a series of invisible processes and interactions. These procedures aim to facilitate cooperation between the kitchen staff and the robots, but their complexity adds an additional layer of articulation work. Articulation work refers to the coordination and collaboration required between humans and machines to ensure effective task completion. The introduction of robots in the workplace necessitates workers to engage in new forms of articulation work, which may involve acquiring new skills and knowledge, such as programming and troubleshooting, as well as adapting to new work processes and workflows. The use of robots fundamentally changes the way work is done, and organisations must recognise the implications of this shift. Understanding the concept of articulation work and its relationship to robots enables organisations to prepare workers for these changes, providing them with the necessary support and resources to adapt and thrive in the evolving work environment [190,192,193]. Contemplating the insights into the challenges and opportunities for improving collaboration between humans and robots in the studied context, from an articulation work perspective, sheds light on the interdependencies and hidden interactions that contribute to the complexity of deploying robots in hospitals. Firstly, it is explored that several challenges emerge in the cooperation between humans and robots:

a. Mismatched expectations: The initial expectation that robots would autonomously carry out simple tasks demonstrates a misalignment between the envisioned deployment and the actual collaboration with staff. This mismatch can lead to confusion and hinder effective collaboration.
b. Comprehensive interactions: The collaboration between robots and staff necessitates a comprehensive set of interactions, which may not be fully understood or anticipated by managers. This lack of awareness can hinder coordination and impede the smooth flow of work.
c. Interdependence: The hidden interdependencies between robots and staff indicate a need for mutual reliance and coordination. The complexity arises from the interplay between human actions and robot actions, which must be synchronised to achieve successful collaboration. By acknowledging these interdependencies and hidden

interactions, stronger collaboration strategies and systems that address the complexity of deploying robots in hospitals, can be developed. If the interdependencies, hidden interactions and invisible work is not acknowledged, it may lead to human non-use of the robots [190,192,193].

5.7.3 Understanding the intricate shaping of work dynamics

Utilising the Leavitt Diamond model facilitates an exploration of the interplay between structure, tasks, people, and technology. The model thereby allows for a holistic understanding of the intricate relationships among various elements shaping work dynamics. By examining these four components, it becomes possible to assess the multifaceted implications of integrating robots into organisational settings [201].

In terms of structure, there is a difference in the structure between OUH and SHS. At OUH, there is a clear division of tasks and a specific person, The TM, responsible for the robots, including troubleshooting and support. In contrast, SHS lacks a designated person responsible for the robots, resulting in confusion and increased workload for the staff.

Regarding tasks, the tasks delegated to the robots at OUH are clearly defined, and the MLT's do not have to consider coordination or delegation of tasks, allowing the staff to focus on their core responsibilities. In contrast, SHS lacks task delegation, leading to inefficiencies. The kitchen staff spends a significant amount of time helping the robots, which increases their workload and reduces overall efficiency. Looking at the people, the individuals at the hospitals are mainly hospital service staff, including kitchen staff, MLT's, technicians, and porters, all holding varying perspectives on the robots. At OUH, the staff members collaborating with the robots perceive them as helping hands that aid and support their work processes. They find it easy to work with the robots, and their expectations align with the capabilities of the technology. In contrast, the staff at SHS has high expectations but encounters limitations and challenges with the robots. This disparity between expectations and reality leads to frustration, disappointment, and a sense of increased workload among the staff. The technology aspect of the model consists of mobile robots. The robots in SHS face numerous difficulties, including inadequate preparations, limited adaptability to the environment, and inconsistencies in performance. This leads to a perception of the robots as complicated and time-consuming sources of extra work. At OUH, the robots are perceived as helpful, cozy, and efficient by the staff.

Applying the Diamond Model, the importance of a clear structure, well-defined tasks, and managing expectations to ensure successful integration and collaboration between humans and robots is highlighted [201]. Based on the relationships analysed between structure, people, tasks, and technology in the context of deploying robots in hospitals, several key insights can be drawn. Firstly, the successful integration of robots into hospital settings depends on a careful alignment between structure and technology. Clear division of tasks, responsibility allocation, and sufficient training and support contribute to a smoother implementation process and improved collaboration between humans and robots. Secondly, the interaction between people and technology is critical. Managing staff expectations, addressing concerns about reliability, and providing adequate preparations and training are essential to ensure acceptance and trust in robotic technology. Understanding staff behaviour and adapting work routines accordingly can enhance the effectiveness of human-robot collaboration. Furthermore, the relationships between people, tasks, and technology highlight the need for adaptability and resilience among staff members. Navigating the limitations of robots through work-arounds and articulation work demonstrates the staff's ability to optimise their work processes and ensure task completion despite challenges [201] [190,192,193].

In summary, successful deployment of robots in hospitals requires a comprehensive consideration of variuos aspects. Managing expectations, aligning structures and technology, and fostering a collaborative environment between humans and robots are key factors for a realistic and effective integration. By understanding the dynamics of these relationships and implementing appropriate strategies and interventions, hospitals can improve efficiency, satisfaction, and the overall impact of robotic technology on healthcare delivery.

5.8 Roles in hospital staff–mobile robot interaction and hospital staff-mobile robot awareness

The following section will discuss the roles the hospital staff are fulfilling towards the robots, in their everyday interactions.
In terms of roles in HRC, the TM from OUH can be characterised as a supervisor, an operator, and a mechanic. He possesses these three roles as he oversees and manages the robot's activities, including monitoring, controlling, and evaluating the tasks performed by the robot. The TM ensures that the robots perform the assigned tasks effectively and efficiently without causing annoyance or frustration. Furthermore, he takes on the role of an operator, responsible for controlling the robot's actions. He possesses knowledge of the robot's location, actions, and the environment in which they operate, and is accountable for the robots' behavior and ensuring proper functioning throughout tasks. Additionally, he operates as a mechanic as he is the one who builds, programs, and maintains the robots. He is responsible for making changes to the robots' hardware and software components, ensuring that the robots' programming is up to date, and addressing any technical issues that may arise.

From an HRI awareness perspective, as identified by Drury et al., type between the TM and the Hubots can be characterised as human-robot awareness, as the TM possesses knowledge about the robot's location, tasks and activities, status, environment, surroundings, and identities, enabling effective collaboration and coordination between humans and robots. Furthermore, he holds awareness and knowledge of the overall missions and the overall goal of the mutual activities carried out by both humans and robots, while facilitating coordinated efforts between humans and robots towards achieving the desired outcome [126].
The kitchen staff at SHS Sønderborg holds some degree of human-robot awareness as they are aware of the tasks and activities of the robots. However, there is a lack of knowledge and awareness regarding the robots' locations, status, and environment. There are no assigned supervisor, operator, or mechanic to oversee the robotic performances, control actions, or ensure proper functioning of Prop and Berta. The absence of these roles contributes to the lack of

robot responsibility in terms of operations and maintenance, which are informally shared among various kitchen staff members. As a result, some staff members take on the role of robot caretakers (kitchen staff) while others may unintentionally sabotage the robots (porter staff).
n the other hand, at SHS Aabenraa, the kitchen staff and the technician are able to monitor the robots, providing knowledge and awareness about the status and location of the robots. The technician functions as an operator, controlling the robot's actions and attempting to trouble-shoot in case of errors. He serves as the link between the developers who have remote access to supervise the robots from their headquarters in America. Additionally, the technician acts as a mechanic, addressing software and hardware issues and errors [126].

According to Randell et al., it can reduce the level of interaction and shared performance, if humans and robots do not hold awareness of each other [127]. For the mobile robot to hold knowledge about the hospital staff, the robots must be capable of receiving instructions and commands and act upon these. In addition, it can be beneficial that the robots in the hospitals are aware of each other. In the case of SHS Sønderborg, SHS Aabenraa and OUH, the robots can be said to hold awareness of each other through zones programmed within the maps the robots navigates via. If a mobile robot is about to enter a zone where another robot is already present, the robot will have to wait for the other robot to leave the zone, before entering.

5.9 Socio-technical considerations for implementing robots at work

The findings of this study shed light on the importance of considering socio-technical aspects when implementing robots to collaborate with humans in hospitals [75].

The deployment of robots into workplaces involves a complex interplay between technology and human factors. From a socio-technical perspective, robots cannot be seen as neutral entities operating independently. Instead, it is crucial to understand them within the context of human experiences and practices. This understanding is essential for addressing the potential impact on human workers, as the use of robots in the workplace transforms the nature of work tasks and is expected to continue doing so in the future. Therefore, it is valuable for organisations, industries, workers, and policymakers to comprehend the potential benefits and challenges associated with the use of robots in the workplace and to develop strategies for managing the transition to a more automated and robot-assisted workforce [67]. Robots can be characterised as agents of change, as they introduce new methods of performing tasks and interacting with work environments for human staff. The specific impacts that robots will have depend on the technology itself, the range of tasks it can perform, and how it is implemented in practice. While the ultimate goal of technology in the workplace is to enhance the productivity and well-being of workers, it is important to acknowledge that the introduction of robots can also lead to job displacement and changes in tasks and responsibilities for human workers. This uncertainty and potential shift in roles may generate anxiety and opposition among human workers, impacting their willingness to collaborate with robots [65][213].

In addition, robots do not only impact the humans who are directly using/non-using them, but they also impact the overall work system, as robots are not isolated machines but part of a larger system, encompassing human workers, organisational structures, and cultural norms [214][67]. Thus, successfully implementing robots in the workplace requires careful consideration of these broader contextual factors, including assessing the impact on work processes, job design, and organisational culture. By taking these factors into account, organisations can integrate robots more seamlessly into existing workflows and foster a collaborative environment where robots and human workers complement each other.

Moreover, the success of human-robot collaboration in hospitals hinges on various contextual factors, including assigned tasks and responsibilities for robots, operating environments, hospital culture and norms, the needs and expectations of human workers and patients, and the technology and design of the robots themselves. Since these factors can vary widely across different hospitals, optimising and improving human-robot collaboration necessitates a deep understanding of the specific context in which robots are utilised. Policy makers, developers, and managers must gain insights into how robots interact with their environment, how human workers perceive them, and their performance in real-world scenarios. This information is crucial for enhancing the design, development, deployment, and integration of robots, ensuring their effectiveness, safety, and acceptance in diverse applications. For example, workflow integration is paramount, requiring robots to support and augment the work of staff rather than disrupt it [214]. By integrating robots into existing hospital processes and workflows, they can be designed to collaborate with hospital staff instead of replacing them. Such an approach allows developers to create socially robust, responsive, and responsible robots that consider the broader social and organisational context and ensure that the robots meet the specific requirements, constraints, and preferences of the staff who will be working with them.

A key aspect of designing robots for collaborative work in hospitals is to prioritise trust and safety. Staff members must have confidence in robots as safe and reliable partners. Trust directly influences the effectiveness and efficiency of work performed by staff and robots and shapes people's perceptions and interactions with robots. It encompasses the level of comfort staff feels when working with robots, the speed at which they adopt new technology, and the likelihood of task delegation to robots. Without trust, staff may be hesitant to utilise robots in hospitals or may use them sub-optimally, potentially compromising aid and efficiency [67].

5.10 Synergies between political and managerial expectations and real-world implementation

As the utilisation of mobile robots in Danish hospitals is on the rise, aiming to automate processes, provide support, and alleviate the workload of the staff, the vision behind incorporating robots into various tasks is driven by the belief that these technological advancements outperform humans in terms of efficiency and speed. Furthermore, robots are anticipated to take over mundane and trivial tasks, thereby relieving employees of these responsibilities. As seen earlier in this thesis, the primary expectation surrounding the implementation of robots in hospitals is the potential to ease the workload and save valuable time for the staff. By delegating certain tasks to robots, hospital employees can redirect their efforts towards more critical and specialised areas of their work, focusing on their core responsibilities. These visions combined with the presence of robots in hospitals generate high expectations among staff members, largely fueled by the promises made by managers and developers.

In general, human expectations towards robots are high, namely due to promises and aspirations from developers, industry, and popular culture, such as science fiction books and movies, often portraying robots as highly intelligent and capable beings, creating a sense of fascination and inspiration towards the technology and what it is capable of, as seen in the Background section of this thesis. Consequently, as technology continues to progress, humans anticipate that robots become increasingly capable and sophisticated, fuelling the beliefs that robots can perform tasks more efficiently, accurately, and tirelessly than humans. As robots represent cutting-edge technology, they evoke excitement and curiosity about their potential capabilities. Humans tend to view robots as something that can make life easier and take on repeatable, dull, heavy tasks while setting humans free. These expectations are shared by decision and policy makers. In Denmark, there are expectations that robots can drive economic growth and provide new opportunities, for example, by automating production processes, leading to increased productivity while reducing costs. Hence, the political focus on technology in Denmark is on how it ought to be administered to continuously maintain Denmark's position in productivity and competitiveness [8–11][12]. To meet these visions, however, it will be beneficial if decision-makers can comprehend that robots need to be acknowledged as more than mere automation technology that can be plugged in and pushed play upon. Rather, robots comprise socio-technical perspectives, demand resources and support, in order to be accepted and adopted in workplaces.

While the initial enthusiasm surrounding robot implementation in hospitals is understandable, it is crucial to recognise the challenges and limitations that arise when integrating robots into complex environments. The practical application of robots within newer application settings, such as hospitals, often reveals unforeseen obstacles and complexities that cannot be fully anticipated during development and testing stages. Reality often falls short of the high expectations, highlighting the need for in-depth research conducted in real-world settings. Conducting research in the wild, or real-world environments, becomes essential to gain a comprehensive understanding of the intricacies involved in human-robot collaboration within hospitals.

Understanding the real-world complexities and limitations of robots in healthcare settings is crucial for managing expectations and informing future developments, bridging the gap between expectations and reality. This PhD study demonstrates the complexity and intricacy of having mobile robots installed in hospitals to collaborate with staff. The unrealistic expectation of hospital management and service staff for robots to effortlessly automate courier processes and seamlessly integrate into the hospital environment necessitates a well-planned and meticulous implementation process. This process includes assuming responsibility, providing staff education, and adapting work routines to accommodate both human and robot staff. It is important to recognise that successful human-robot collaboration cannot be achieved through

a simple plug-and-play approach. One of the keys to the successful deployment of robots in hospitals is understanding the dynamics between humans and robots, as well as user expectations and interactions in various situations. The expectations towards robots in hospitals often stem from techno-optimistic visions of developers and hospital management, hoping that the technology can increase efficiency, reduce costs, and relieve staff. However, real-world scenarios are often quite different, as seen throughout the findings of this study and earlier studies of robots 'in the wild.' When the great expectations encounter the harsh realities of the real world, they often result in disillusionment, frustration, and a sense of resignation and disappointment.
As seen in the findings of this study, articulation work becomes prominent in the context of human-robot collaboration in hospitals, as the staff anticipates that the mobile robots will offer a simple and seamless solution, smoothly integrating into the real-world environment and providing valuable assistance. However, the study reveals that at SHS, the staff's expectations of collaborating with robots in practical scenarios exceed the capabilities of the robots, leading to a mismatch between anticipated benefits and actual outcomes. Three primary factors contribute to this disparity.

Firstly, the preparations made by the hospital and robot developers to adapt the robots to the specific hospital environment are inadequate. Insufficient attention to the contextual factors and challenges faced by the staff raises their hopes and expectations, only to be met with limitations and shortcomings in the robots' performance. The disparity between the staff's high expectations and the robots' actual capabilities leads to disappointment and frustration. Secondly, the robots are sensitive to staff behavior, which further exacerbates the challenges. The staff's attempts to collaborate with the robots are hindered by the robots' inability to effectively respond to their actions and adapt to their needs. This sensitivity to human behavior creates additional barriers and prevents the staff from seamlessly integrating the robots into their work routines.

Finally, the staff finds themselves unable to rely on the robots for assistance in their daily tasks. The robots' limitations and inconsistencies in performance make it difficult for the staff to depend on them as reliable partners in their work processes. Instead of relieving the staff's workload, the robots become an additional source of frustration and inefficiency. In contrast to SHS, OUH demonstrates a well-established and efficient integration of robots into their daily operations. This emphasises the importance of understanding and managing the expectations of humans when deploying robots into work settings. It is crucial to align the staff's expectations with the capabilities and limitations of the robots to avoid disappointment and disillusionment. Moreover, adequate preparation and adaptation of the robots to the specific work environment are essential to ensure their seamless integration and successful collaboration with human workers.

The concept of workarounds and articulation work becomes prevalent as the staff attempts to navigate the challenges posed by the robots' limitations. The staff has to find alternative strategies and methods to compensate for the robots' shortcomings and fulfill their tasks effectively. This improvisational and adaptive behavior reflects the staff's resilience and their ability to adjust their work practices in response to the introduced technological changes.

Thus, this PhD study highlights the significance of considering the socio-technical aspects and managing expectations when implementing robots in hospital settings. By addressing the factors that contribute to the disparity between human expectations and robot capabilities, such as inadequate preparations, sensitivity to staff behavior, and the inability to rely on the robots, we can achieve a more realistic and effective collaboration between humans and robots. Understanding the dynamics of workarounds and articulation work allows for the development of strategies and interventions that enhance the integration of robots into everyday work routines, ultimately leading to improved efficiency and satisfaction for the hospital staff.

6 CONCLUSION

The present PhD project contributes to the knowledge on human-robot collaboration in practice; in the wild; in hospitals. Specifically, the project elucidates the complexity of the collaboration, subsidising understandings of the dynamics and interplays between staff and robots working together, in this case at hospitals in Denmark. As the study highlights the challenges for both robots, humans, practices and ecosystems surrounding them, the study contributes to the future shaping of collaborations between staff and robots in real-world settings. Conclusively, the findings from the PhD study, sorted by paper, show that:

Paper I

- The deployment of robots for human cooperation goes beyond task automation and requires an understanding of the work changes they bring.
- Cooperation between hospital staff and robots often face challenges because of invisible steps of work and unrealistic human expectations towards the robots and their efficiency.
- If the robots are not carefully supported, there is a risk they increase the workload of staff, as staff will have to take care of the robots, on top of the tasks they are already performing.
- The cooperation between humans and robots in hospitals is influenced by environmental factors, behavioural factors, and factors related to human reliance on robots. Understanding these factors and addressing socio-technical considerations are crucial for successful human-robot cooperation in real-world environments.

Paper II

- Socio-technical factors are crucial to consider, to ensure the success of robots in real-world environments, including the specific practices in which robots are involved and the associated elements. This includes acknowledging human adaptations, accommodating environmental changes, and understanding the impact of robots on the overall environment.

Paper III

- Effective collaboration between hospital staff and mobile robots in hospitals, relies on clear division of responsibility and appropriate environmental infrastructure. Assigning onsite personnel dedicated to supporting and troubleshooting the robots is crucial for their ability to assist humans effectively. Without a safety net, such as an engaged technical manager, frustrations and anger may arise among hospital staff working with

robots. Additionally, tasks should be clearly defined and distributed between humans and robots to avoid confusion or uncertainty about when and how to involve the robots.
- When essential elements are in place, humans collaborating with robots can personalise their interactions, ascribing particular qualities and characteristics to the robots, thereby strengthening the relationship and teamwork between the parties involved, improving the quality of the task execution.
- It is vital for the environment to be suitable for both humans and robots to ensure successful teamwork. Narrow hallways, for example, can pose challenges and lead to frustrations and disruptions in task performance for both humans and robots. When the settings are well-suited for both parties, the collaboration can flow smoothly.

Paper IV

- Human-robot collaboration in hospitals is a multifaceted, socially influenced phenomenon, hence the interaction between many different factors and the focus on social dimensions are crucial in understanding the collaboration.
- By acknowledging the complexity of human-robot collaboration, researchers and practitioners can gain insights into the intricacies of the collaboration in hospitals. This understanding can inform the design, implementation, and successful integration of robots in healthcare settings, ultimately enhancing the effectiveness and acceptance of HRC in hospitals. There is genuine need for a comprehensive understanding of the implications and challenges of incorporating robots into human work environments. By recognising the complexity of human-robot interaction and considering the broader context, successful integration and collaboration between robots and staff can be achieved. These findings are vital to consider ensuring appropriate development, implementation, and use of robots in hospitals, as there is a need for understanding what the parties do, when they do what they do, for the delegation of work, coordination of forces and organise of tasks and thereby ensure both humans and robots to constitute the best possible conditions for collaboration.

7 IMPLICATIONS

This PhD study aims at analysing and identifying phenomena and elements that contribute to a deep understanding of the practical challenges and opportunities when robots and humans collaborate in hospitals. Aligned with a pragmatic research approach, the insights and understandings gained through the study are used to generate implications for practice, with the hope of improving the quality of collaboration between staff and robots, both within hospital settings and beyond. In this section, I delve into the practical implications that arise from exploring human-robot collaboration in the wild, specifically in a hospital environment. Through this exploration, I investigate various aspects such as task allocation, coordination, communication, and the impact of robots on staff workflows. This inquiry into complex human-robot interactions allows for the identification of barriers that hinder seamless integration. By gaining insights into the practical challenges and opportunities associated with robots and human teamwork in hospitals, I formulate concrete implications aimed at enhancing collaboration and on-site effectiveness. The following are the presented implications:

In general, robots are implemented in hospitals and other workplaces to improve the working environment, increase efficiency, and enhance the quality of work performed by staff, as they allow workers to have more time for core tasks. In hospitals, mobile robots are deployed to handle logistic tasks such as transporting supplies, dishes, and cutlery, as well as urine and blood samples. In some cases, it succeeds, while in others, it appears that the introduction of robots in hospitals is a difficult knot to untangle. The deployment of robots in hospitals can be influenced by a multitude of factors that play a significant role in the process. Factors, that may not have been necessarily considered at the hospitals before suddenly finding themselves with a robot that has increased the workload for the staff and made their efforts less efficient, as the employees now have a new task: assisting the robots.
Through this PhD study I have found that to prevent this from happening, certain fundamental elements need to be in place, respectively the division of tasks, robot responsibility, education and environmental factors. These elements will be outlined below.

7.1 Division of tasks

The tasks performed by both employees and robots must be planned and transparent. This will require the organisation to have an overview of which tasks can and ought to be carried out by robots and which tasks must be performed by humans. Such mapping will create certainty that robots are transforming and changing work rather than being a simple plug-and-play automation solution. For example, kitchen staff at SHS have been given new tasks after mobile robots were introduced to the hospital. They are now responsible for sending the robots off to fetch carts in the hallways. They have been tasked with placing the carts in specific locations on the corridors to ensure proper positioning for the robots to pick them up. They monitor the robots to ensure they perform their tasks correctly and address any instances where the robots are standing still in the hallways. They walk alongside the robots to ensure that everything goes without errors, during the cart transportation process. If they do not do so, the workload may accumulate. For instance, if a robot repeatedly gets stuck in the hallway with a load of dishes throughout the day, it will cause delays in dishwashing tasks. The employee on the last shift of the day risks being burdened with numerous additional tasks because the robots did not complete their assignments, thereby further delaying the remaining tasks for the day. This could possibly be avoided, if such phenomena were mapped and used as an overview to delegate and divide tasks among staff and mobile robots,

7.2 Robot responsibility

The responsibility for the robots (such as who oversees fixing errors or restarting robots if something goes wrong) must be established. This way, staff know who to contact if they notice, for instance, that a robot has stopped functioning in the hallway or other errors. Thus, at least one (depending on the number of robots) dedicated person onsite to take on the role as Robot Responsible, being someone who can take care of the robot as soon as something happens to them and troubleshoot in case of error. Moreover, the Robot Responsible must seek to prevent errors.

These tasks should be explicitly assigned and delegated to individuals who can ensure that the expectations are effectively fulfilled and the allocation of responsibility for robot operations, as well as the overall management of robots, must be treated with utmost seriousness.

7.3 Education

Staff need to have knowledge about how robots operate and understand why they behave the way they do (such as waiting for each other outside specific zones). This way, staff are aware that there is nothing wrong with the robot if it remains stationary in the hallway and does not enter a particular department, for example. While staff must receive training/knowledge on how to operate robots and enhance their understanding of these, managers must be aware of how the robots contribute to the team performances, including how they affect work processes and flows. This awareness must not be obtained by solely listening to developers, managers must listen to 'the man on the floor', both technicians and staff collaborating with the robots and take other factors into account, for example environmental ones.

7.4 Environment

Additionally, the physical surroundings need to be well-suited for robots to operate in. There should be ample space for the robots to manoeuvre, and space for staff and robots to coexist without issues. The robots should not obstruct human movement or become bothersome in any way.

When these things are in place, it will create an environment where robots can fulfil the visions they are deployed to fulfil. This fulfilling of visions has been observed at OUH, where robots rather seamlessly integrate into daily routines and handle transportation tasks. This achievement is possible due to several interdependencies. There is clarity regarding which tasks belong to the robots and which tasks belong to staff, further facilitated by that the MLT's - for whom the robots transport samples - have never had to transport samples themselves. It has always been the porters who handled this task. However, the porters seemingly have numerous other

tasks to attend to at OUH, making them content with the robots handling the transportation of blood samples.
The MLT’s emphasise the speed and ease of sample transportation now that they don't have to burden humans with the tasks of running back and forth with samples – and they are confident that the robots perform their work reliably. This confidence exists mainly because of the presence of the Technical Manager who promptly addresses any deviations or errors the robots may encounter, ensuring that they are immediately rectified. He takes robot responsibility. Hospital staff can trust that the robots perform their tasks because they know there is a competent person monitoring them. They are aware that the TM has the takes care of the robots, and they know they can always reach out to him if needed. This assurance allows them to have confidence in the robots' performance and provides a sense of support and assistance whenever required.
They are free to focus on their core tasks, rather than caring about overseeing the robots. Further, some of the hospital staff members at OUH have attended robot training courses with the TM and are familiar with the basics of robots, such as why they might stand in front of the elevator waiting for a while. When they understand the reasons behind such behaviours, they no longer become irritated when they see a robot in that position. Their knowledge about robots' functioning helps them develop a deeper understanding and patience, minimising potential frustration or annoyance.

8 LIMITATIONS

The findings of the PhD project are limited by several factors.

First, the number of participants in the studies could have been higher, especially the number of participating experts. The study held four expert interviews, but as the included informants were the main experts in the included hospitals, the relatively lower count was deemed acceptable. Further, it became evident that the interviews resulted in the emergence of distinct patterns and narratives, with limited new insights gained. This suggests a state of saturation, where additional interviews are unlikely to contribute substantially to the existing knowledge. In addition, the distribution of informants across gender and age was deemed satisfactory, thus fulfilling the required diversity. However, it is worth noting that conducting additional interviews could have potentially provided a more nuanced understanding of the findings and introduced valuable new perspectives. In addition, other relevant informants could have provided additional knowledge, the study could have benefitted from. For example, it could have been beneficial to include patients' points' of view on robots in hospitals, in order to make an ecological analysis which likely could have provided the study with even richer data. However, the scope was limited to hospital staff who were in direct contact which the mobile robots, at they were able to provide insights on the direct interactions with the robots. Consequently, the limitation of these studies lies in the relatively small number of participants, which may impact the comprehensiveness of the results.
In addition, utilising convenience sampling has limitations that should be considered as well. This way of sampling often leads to non-representative samples, as participants are selected based on accessibility rather than representativeness. This can result in biased findings that may not apply to the larger population. Sampling bias is another concern, as I may unintentionally have chosen participants who are more cooperative, have something to express (such as anger) or readily available, skewing the perspectives obtained. However, as this study emphasises in-depth qualitative insights and rich contextual understanding, convenience sampling still yields valuable data and offer nuanced insights into the experiences, perspectives, and practices, this study is concerned with.

Second, the type of robot focal in this study, mobile (service) robots, can be considered a limitation, as the findings may not fully capture the complexities and nuances of human-robot cooperation in hospitals, but rather a comprehensive understanding of the collaboration between service staff and mobile robots. Hence, the presented findings might not apply to cooperation between other types of robots and humans in hospitals.

Thirdly, time constraints have potentially limited the extent of research in comprehensively exploring all aspects of HRC in hospitals within the designated timeframe. Future studies could address this limitation by extending the research duration and conduct longer ethnographic studies, to gain a more comprehensive understanding of HRC in hospitals, not least the dynamics and interplays between staff and robots, and how these are linked to practices in hospitals.

Further, a limitation is concentrated around the time I went to fieldwork at SHS Aabenraa: it was during the Danish summer holiday and there were limited activities taking place in the hospital. In addition, the hospital was under reconstruction and the majority of the robots were put into their docks, without operating, to make room for workmen. Consequently, the amount of data gathered through observations, guided tours and shadowing was limited.
The lack of a longitudinal perspective in the study focused mainly on the present state of HRC in hospitals. Considering the long-term implications, evolution, and sustainability of HRC over time would offer deeper insights into the dynamics and outcomes of human-robot collaboration in the included hospitals which would have been valuable. Hopefully I will get a chance in the future to revisit the hospitals I had conducted fieldwork in and explore how the collaborations and relationships between staff and robots have developed over time, facilitating the examination of the evolution and sustainability of HRC, as well as any changes in attitudes and perceptions among hospital staff.

Another limitation in this context is the absence of validation from experts, informants and academic peers, which could have enhanced the strength of the results. A general criticism pertaining to the studies encompassing this PhD project is that the data analysis was solely conducted by me, thus relying solely on my limited perspective. Engaging in collaborative analyses and interpretation processes could have qualified the material and shed light on additional aspects. In other words, collaboration could have potentially improved the quality of findings and data by benefiting from multiple perspectives. While my supervisors provided valuable critiques at a later stage, an overall lack of collaboration in the research process is a weakness of this project.

As an educated techno-anthropologist, I am trained in bridging the gap between humans and technology and analyse the complexities that lies herein. I have professional experience with analysing technology used in hospitals and therefore held some knowledge of the norms, values and scientific approaches within hospitals, before I started this PhD study. As a result, it is possible that certain elements, which required further clarification, were not pursued in the interviews due to a presumption of already possessing a comprehensive understanding of the informants' discourse. However, it should be noted that I was conscious of this limitation and made efforts to gain in-depth insights into the perspectives of the informants and understand their worlds.
In addition to the methodological limitations mentioned earlier, the application of quantitative studies could have greatly complemented and strengthened the findings in this research on human-robot collaboration (HRC) in hospitals. One possible approach that could have been employed is the use of surveys to investigate HRC in hospitals. A well-designed survey could have been developed to gather quantitative data on various aspects of HRC, such as the frequency and nature of human-robot interactions, perceptions of robot performance, user satisfaction, perceived impact on workflow and efficiency, and attitudes towards robot integration. To ensure a comprehensive perspective, a representative sample of hospital staff from different roles and departments could have been selected. This would involve reaching out to nurses, doctors, technicians, administrators, and other relevant personnel who interact with robots in

their daily, through which a more holistic understanding of HRC in hospitals might have been obtained. In terms of data collection, validated scales and measurement tools could have been employed to assess variables of interest. For example, Likert scales used to capture participants' attitudes and perceptions, or rating scales to evaluate the effectiveness and usability of robots. This would have allowed for a standardised and systematic assessment of HRC experiences in hospitals, allowing for various statistical analyses, such as descriptive statistics, correlations, and regression analysis. These would have provided insights into patterns, relationships, and associations between different variables, enhancing the understanding of HRC dynamics in hospitals.

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10 APPENDIX

10.1 DANISH POLITICAL STRATEGIES

The main subjects and focus areas in the Danish “National Robotics Strategy: Good educational, research, and innovation policy frameworks for robotics technology in Denmark” from 2020 [9] is outlined in Table 13.

Table 13 Subjects and focus areas in the strategy [9]

MAIN SUBJECT	FOCUS AREA
Research and innovation	Research, innovation, development and demonstration in the field of robotics Technological service for Danish companies that develop and use robots. Better overview of access to research infrastructure Better access to ESA and NASA for Danish robot researchers and companies
Access to competences	Strengthened robotics skills through continuing education and in-service training.
Internationalisation	Strong Danish participation in the EU's framework program for research and innovation Access to world-leading robot environments via the Danish innovation centres Attracting foreign investors Tailored export promotion offers.
Use of robotics in Danish companies	Knowledge of barriers to companies' investment in automation and employees' skills Strengthened innovation in business through knowledge collaboration in cluster organisations and innovation network.

In the strategy it is visioned that Denmark must have a strong framework for developing and using robotics solutions, especially in relation to the green transition, with emphasis on industry, agriculture, construction, and transport. It is briefly mentioned that robots can contribute with cleaning and performing logistic tasks in hospitals, allowing workers to have several good years on the labour market than earlier.

The strategy points out that the use of robotics technology calls for the need for involvement and understanding between technical, law, social and economic conditions, as robots are gradually engaging in close collaboration with humans.
In addition, the strategy describes that in the future, there will be a need for researching how emerging technologies can be used to create greater healthcare, in terms of more effective use of resources and development of user-oriented solutions, emphasising the need for analysing the consequences for society in general and citizens in particular.
Scrutinizing Danish political strategies for robot-related content, the discoveries are limited. There are no other dedicated political strategies for robots in Denmark, but earlier political strategies about growth and digitalisation briefly touches upon the subject. These are outlined in the following tables.

In the strategy from 2018, "Strategy for Denmark's digital growth" [13] from the Danish Ministry of Industry, Business and Financial Affairs, it is described how Denmark must be a digital frontrunner, through 38 focus areas, clustered in six main subjects, as displayed in Table 13.

Table 13 Subjects and focus areas in the strategy [13]

MAIN SUBJECT	FOCUS AREA
Digital hub for a strengthened growth environment.	Digital Hub Denmark – partnership for digital growth Review of depreciation rules for IT and telecommunications equipment Strengthened research, which promotes new technological. options and solutions National strategy for digital research infrastructure
Digital boost of SMEs	SME: Digital – program for digital transformation and e-commerce in small and medium-sized businesses Disseminate knowledge about new robot technologies for small children and medium-sized companies. Development of international standards for small and collaborative robots Increased focus on digitisation in the innovation system
Digital competences for everyone	Technology Pact – competences for a technological and digital future Experimental program on enhanced technology understanding in the elementary school. Center for the use of IT in teaching at vocational training Increased focus on digital skills in business

	the final examinations of the programmes Digital strategy for higher education Action plan for several graduates from higher education STEM courses Greater use of satellite-based data in higher education educations
Data as a growth generator – Free access to DMI's data	Clear guidelines for companies' data use Development of data ethics recommendations Block-chain solution for ship register and certificates. Digital export certificates Experiment with put & take database for tourism data. Free access to DMI's weather, climate and ocean data Digital spatial planning and planning data Experiment with data rooms for sharing data between companies and authorities Analysis and testing of business potential in selected. public data
Agile business oriented regulation	Regulation that enables new business models Digitisation for the benefit of consumers Digitisation-ready Competition Act Ensure competition and prevent market abuse among digital platforms Innovation-friendly digital single market in the EU Strengthened efforts against digital trade barriers on a global level. Strategy for digital construction Learning site about tax returns for beginners companies Tax folder for companies Continued streamlining of property registration. Faster case processing via machine learning in the Swedish Safety Agency Analyse the possibilities for adaptation. of the rules for outsourcing for financial companies
Strengthened	A boost to IT security in small and medium-sized companies

IT security	One digital entry for companies' reporting of IT security incident

In the strategy, the Danish government sets the direction for how Denmark can seise opportunities in digital transformation, job creation and greater growth and prosperity. The goals expressed in the strategy is, that Danish businesses must release the growth potential in digitisation; provide everyone with the tools needed for engaging in the digital transition; and ensuring the best conditions for businesses engaging in the digital transition. The strategy is not directly concerned with robots, but briefly mentions that robots can take on physically demanding work in industry and businesses.
The strategy emphasises that technology is changing the job market, as this has been constantly evolving in response to technological progress - digitalisation is expected to be no exception. This transformation will take various forms and for instance, a significant proportion of work tasks will become less strenuous, and the boundaries of traditional work hours will be blurred, as technology enables individuals to work remotely, using mobile devices such as tablets and smartphones. Furthermore, an increasing number of work functions and duties will be automated, thus raising the bar for workers to acquire new competencies and specialise in particular areas. One of the technologies transforming the job market, is Artificial Intelligence (AI).

In 2019, the Danish Ministry of Finance and the Danish Ministry of Industry, Business and Financial Affairs published "National strategy for Artificial Intelligence" [10], highlighting that Denmark must take the lead with responsible development and use of artificial intelligence, for example for use in robotic solutions.
The strategy lays the groundwork for how Denmark can get the most out of the potentials AI technology holds, to support Danish companies' competitiveness, ensuring a continuous rating among the most prosperous countries, and a public sector able to provide high-quality service to citizens. The vision is that Denmark leads the way in responsible development and use of AI. This is to be realised through four main subjects as seen in Table 14 below [10].

Table 14 Subjects and focus areas in the strategy [10]

MAIN SUBJECT	FOCUS AREA
A responsible foundation for artificial intelligence	Ethical principles for artificial intelligence Establishment of the Data Ethics Council Security and artificial intelligence Legal clarity in the development and use of artificial intelligence Transparent use of artificial intelligence Ethical and sustainable use of data in business Danish influence on standards for artificial intelligence

More and better data	Common Danish language resource Better access to public data More data in the cloud for artificial intelligence Better access to data abroad for Danish companies and researchers.
Strong competencies and new knowledge	Dialogue with research funding agencies on artificial intelligence Strengthened digital competencies in the state. Strong Danish participation in the EU's framework program for research and innovation Strengthened digital competencies through adult, continuing and further education.
Increased investments in artificial intelligence	Signature projects Strengthened investments in Danish companies. Exploration of the possibility of an investment agreement with the EU Increased knowledge sharing across public authorities. Denmark as an attractive growth environment

These subjects and focus areas are prioritised in healthcare, energy and supply, agriculture and transport. It is stated in the strategy, that Denmark is recognised as one of the most advanced digital countries worldwide and the country plans to leverage this position by attracting knowledge and technologies related to artificial intelligence (AI). Further, Denmark will be collaborating with other Nordic and European countries to encourage responsible AI development and it is described how failure to act quickly and carefully may lead to losing the competitive edge and influence in the field of AI. Thus, rather than emulating the US and China, which invests heavily in AI with minor regard for ethics, responsibility, and privacy, Denmark intends to prioritise these principles to create a favourable framework that utilises the growth potential of AI, in its established international strongholds, keeping Denmark at the forefront of AI innovation.

Another strategy briefly touching upon robots, is the joint public digitalisation strategy "Digitisation that lifts society - the joint public digitisation strategy 2022-2025.", in which the government's, the municipalities' and the regions' visions that digitalisation should be a central part of the answer to the major societal challenges facing Denmark – are outlined. Data and new technology should be tools to aid the shortage of labor, contribute to the green transition of and support the development and maintenance of the welfare state, including the healthcare system. This entails using data and new technology to optimise the use of energy and resources, create new workflows, and ensure that employees can use their working hours on performing core tasks. The strategy holds four visions and 28 initiatives, these are displayed in Table 15 below [11].

Table 15 Subjects and focus areas in the strategy [11]

VISION	INITIATIVES
A cohesive and user-friendly digital public sector for everyone	Inclusive and Cohesive Digital Service Easy and Secure Use of Powers of Attorney A Unified and Personalised Overview for Citizens Easy and Secure Use of Consent Improved service through digital mail Better digital access for all parents responsible for children Digitalisation of the driver's license area Continuous course of action for vulnerable children and young people Better communication and knowledge about effects on the specialised social area via new address index Better access to health data for citizens and health personnel Digital solutions to support more treatment at home. Implementation of a national guide for health apps Data for quality development of the near health care system Digital access for parents to children's health information Strengthen the development of a comprehensive patient overview. Transition to a new disease classification in Denmark Modernisation of digital messages in healthcare
Digitalisation to alleviate the shortage of labor	New technological solutions to support labor shortage
A digital contribution to the green transition	Data-driven transition to a circular economy Digital platform for building materials and raw materials Further development of energy and co2 accounting Better use of supply data for energy-efficient buildings Green data processing and storage

A strong foundation for digital development	A common public effort for better access to public data Strengthened Danish language technology. Strengthened anchoring of cyber and information security Strong digital foundation for the public sector A responsible basis for application of new technology

The strategy emphasise that use of data and new technology must be done in responsible ways, based on the societal values in Denmark. In addition, transparency must be focal, in order to maintain a high level of trust, characterising Danish society. Digitalisation can make Denmark more vulnerable - both as a society, for example due to cyber threats, and as individuals, where some citizens may find digitalisation and the use of digital solutions difficult. Therefore, the strategy states, Denmark must continuously design public services for everyone, regardless of digital skills, to have equal access to the welfare society, ensuring a digital foundation that meets new digital threats. Robots are shortly mentioned in a single section, communicating that the Danish public sector increasingly is implementing well-known technological solutions such as automation, artificial intelligence, and robotics and there still is a significant potential to further enhance these technologies. To address the anticipated labor shortage in citisen-related welfare, the state, municipalities, and regions have agreed to launch a 10-year plan aimed at introducing new technology and automating the public sector.
Further, the strategy state that the healthcare sector, the state, local governments, and regions will continue to work together to advance the digitalisation of the healthcare system [11]. In relation to this, the strategy "Strategy for Digital Health - A coherent and Trustworthy Health Network for all," will be extended until 2024, accompanied by several concrete initiatives intended to promote greater coherence and proximity in the healthcare system [12]. These initiatives will leverage the power of data and digital solutions to support the overarching objective of establishing a more unified and effective healthcare system. The strategy for digital health outlines a set of five focus areas, holding 27 efforts, that are intended to achieve the overarching objectives of prioritising patient needs and simplifying daily workflows for healthcare professionals, as displayed in Table 16.

Table 16 Subjects and focus areas in the strategy [12]

FOCUS AREA	EFFORT
	The doctor in your pocket –A GP app for patients Ask the patient – Patient Reported Outcome (PROs) Digitally supported rehabilitation A complete presentation of the

The patient as an active partner	patient’s health data A guide to health apps Decision support tools for cancer patients Digital pregnancy tool
Knowledge on time	Better, faster and more secure digital communication across the sector A complete overview of a patient's care and treatment Digital workflows at GPs and more targeted communication with other parts of the health care sector Safer medication at residential care centres and substance abuse rehab centres Better overview by having structured care records in the municipalities.
Prevention	Digitally supported early detection in municipal elderly care Data-driven technologies for automation, prediction and decision support Digital decision support for prescribing medication Continued roll-out of telemedical home monitoring Digitally supported care plans for patients with chronic illness Better follow-up on vaccination and cancer screening programmes
Trustworthy and secure data	Patient access to log information from hospitals Improved digital security – joint initiatives aimed at better cyber and data security across the health care sector. Better patient control of information shared across the health care sector. IT security at the General Practitioner Modernisation of IT security standards in the health system

Progress and common building blocks	Digital welfare solutions distributed to patients. Long-term vision for the common IT infrastructure Better overview of organisational units in the health care sector Establishment of a national substitute - Civil Registration System (e-CPR) solution

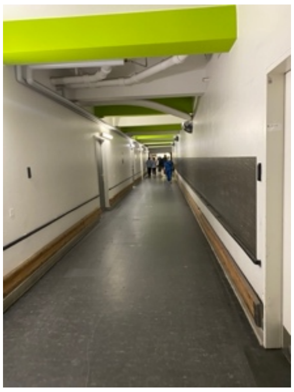
10.2 SELECTED FIELD NOTES

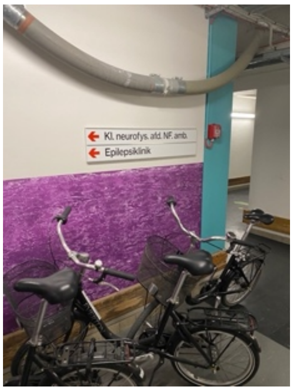
In the following, field notes from OUH are inserted. The field notes from OUH are included as they have been meticulously prepared and are presented in a manner that is understandable to the recipient. The field notes from OUH have undergone a thorough process of refinement, ensuring that they are organised, structured, and formatted in a way that allows for easy interpretation and understanding by the intended audience. These notes provide valuable insights and contribute directly to the research findings and conclusions presented in this thesis. On the other hand, the field notes from SHS are more akin to field jottings and may be challenging for anyone other than myself to comprehend. The field notes from SHS may not possess the same level of clarity and coherence, as they are in the form of fragmented thoughts, and unstructured entries that were recorded during the field work. While these notes are undoubtedly valuable for me in capturing insights and understandings, their inclusion in the appendix could potentially confuse or mislead the reader who lacks the necessary context and familiarity with the research process. Therefore, only the field notes from OUH are included, to maintain clarity and coherence in this Appendix. Further, it ensures that the reader can easily follow the flow of information, understand the observations made, and grasp the relevance of the findings without unnecessary confusion. The inclusion of meticulously prepared and organised field notes from OUH also demonstrates a rigorous approach to data collection and analysis, further enhancing the overall validity and reliability of the research presented in this report. Hence, it is important to note that while the field notes from SHS are not included in the appendix section of this thesis, they are still accessible upon request.

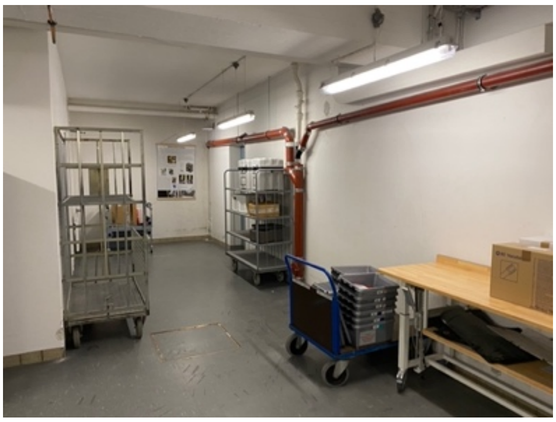
Field notes from OUH 29.11.2022-30.11.2022

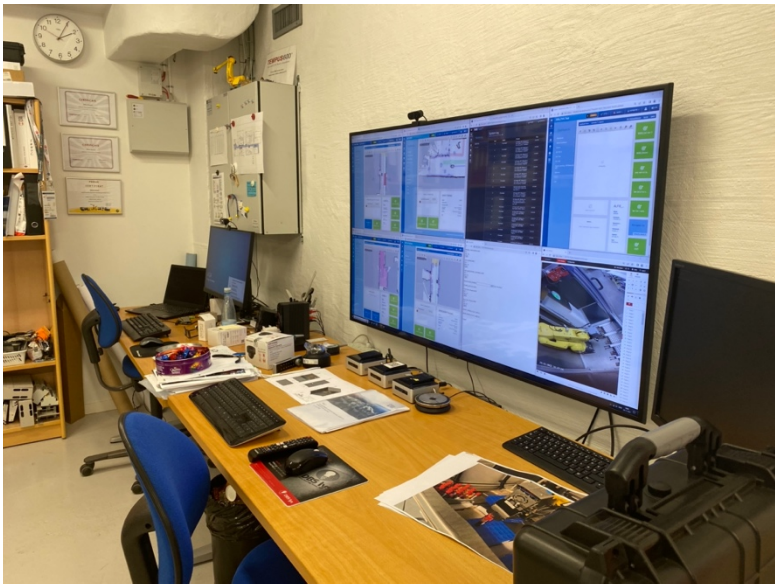
On November 29th at 8am, I arrived at OUH, Building Maintenance, checked in at the welcome screen (Picture 1). Esben is informed that I am here - he comes and welcomes me. "Yes, sorry it took a bit of time - the corridors here are long. Do you have good walking shoes on?

You'll be walking a lot today," he says. I am prepared and have running shoes on - because I have heard that the robots at OUH run long distances every day - and my plan is to follow them while they do what they do. We go through the tunnel. We talk about where I stayed and morning traffic. We pass a porter on a truck, greet him. "Have you been here before?" asks Esben, I say no. He tells me that there are 5 km of corridors under the hospital and that almost all buildings can be reached via the tunnel. "I barely see daylight again before I get off work," he says. "But you don't have robots down here?" "No no no, we don't have that, it wouldn't work! Mainly because of the trucks, but also because the corridors are too narrow for robots. We also did some tests, and it just doesn't work." Esben shows me a rolling gate and says that if a truck comes driving here, next to the gate and there is also a robot, there is no room for any of them. "The robots run on the ground floor and 1st floor." So they run a lot among people?, I ask, and Esben says "Oh yes, they do, yes. But down here, the trucks drive extremely fast, beds take up space, carts and cyclists, everything - it doesn't work to have robots in a place like this." We continue and greet people in the basement as they pass us on bikes and trucks. Now we are almost at Esben's den: the robot workshop where he stays. "So here we are - and if you need to come in, the code is xxxxxx - and you can just come in whenever you want. Do you want a cup of coffee?"









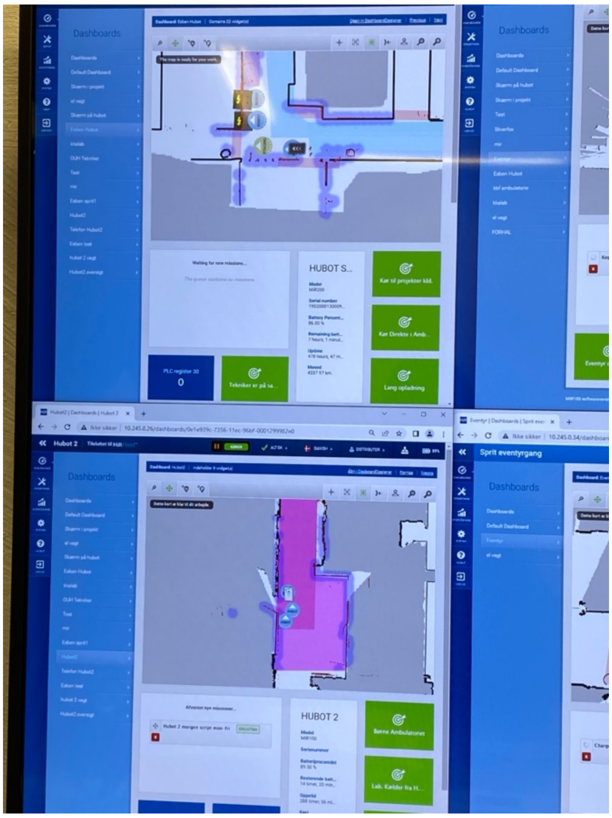
See, this is the command center!" Esben shows me his two desks that are set up against the wall, on the wall is a large screen with a real-time map of the robots, so Esben can see where they are, if there are any around, if it is too close to something, see its current tasks and monitor the robots' actions.

Esben's den is an inferno of clutter, robots, cables, boxes, notes and drawings, tools, magnets and buttons, screws and small things, small robot figures, coffee in the pot, empty bottles, pictures of robot gear, prototypes, wires and gadgets. He gives me a lab coat that smells characteristic of a hospital, "This one is completely clean. Just put it on, then you can walk around freely without anyone asking questions. Then you can look like a doctor," he says.

We start talking about robots. Esben tells me that they have Hubot1 and Hubot2 - Hubot1 has been running at OUH for four years, Hubot2 was put into operation in the fall. MiR-200 robots. I notice a poster with Hubot on it, including specs and speed - and I ask why they run relatively slowly. "It's because you can overtake them when you're walking at a brisk pace. So they don't bother you too much." It turns out that non-bothersome robots are something Esben strives for. "If you just increase the speed a bit, you can easily pass it. It was a little more annoying if it followed you all the time. We don't want annoying robots. When we started with it in the past, Hubot 0.5 m/s - I have slowly and calmly turned it up and then- look, now the robot is on its way into an elevator!" says Esben and points to the screen on the wall. We sit down and watch Esben's screen.

"So, it actually just runs around and takes care of itself - and it's the staff that says what it should do, they say drive there." "Do they have a screen or how do they do it?" "Yes, they do, but on both robots, there is a phone that they use to send the robot away. But they also have a screen on their computer, where they can also go in and do it. And then they can also follow it, see where it is, see if something is in the way etc."

"The clouds and the red, that's what its sensor sees. A table leg or someone walking around. These are things that were not programmed in when it got its map made. It's not necessary to code them in for it to be able to navigate. The black is where it has been told it can drive, that's how the map looks. So, it compares and measures that it can see an edge there and the red - and then it calculates where it can drive. And using the black, it knows where on the map it is. There are four maps it uses to navigate. And I have added stopping places so it knows where it should drive to stop. For example, down in the laboratory, it has its fixed place where it stops when it arrives. See, you can see the red dots here, those are people coming out, you can see their feet on them. That's because when it gets to where it should, it plays a sound and then they know it has arrived. So, they usually come pretty quickly and empty it of samples. And then it can also send text messages and it can also send an email.." "What if no one comes?" "No, but it will stay there now until someone comes and tells it what to do next. Because now it has samples that the people who sent it - look, now they're moving their feet, now they're standing by this one at the end, opening the cabinet, emptying the cabinet of samples, and then they'll just tell it in a moment what to do next. Because it may be that there are samples going to other laboratories, so they'll send it there. But if it's empty, they'll send it back to the outpatient clinic again. So it just drives all the way back again. So it just waits for something to do, for someone to assign it to something."



"Who are they assigned to? Blood samples and biochemistry. Hubot goes to the outpatient clinic where the outpatients come in and have their blood samples taken. They take about 2000 blood samples a day there in the Outpatient clinic. There are 15 booths where you are called in with a number, you sit down and they take a blood sample. The majority of them are put into a delivery system we have, which blows the blood sample directly down to the laboratory. And then we have about 200-300 samples a day that are used for research. They can't go with the blowing system; they have to be put on ice or in heating devices or three have to be collected that have received the same treatment. They used to carry them before. And that's where the robot has been put in place instead, because they actually used up to 2.5 hours a day carrying them."

"Is the robot operation safe enough for you to trust it with such tasks?" "Yes, yes. And see, on this screen we can analyse the runs. For example, we can see how far they drive. Now we can just generate an overview here, so we can see that today it has only driven 720 meters so far - yesterday it had plenty to do, it drove 7.1 km - and that is from 7 a.m. to 4 p.m. Every single morning, 365 days a year, the robot goes up to our intensive care unit. It is pre-programmed to do so. We have three intensive care units where it goes up and stands, sends a text message to the on-duty person, that it is there - then they go out and put in the morning blood samples they have taken on the intensive care unit. They don't have to do anything; it drives itself down again. They don't have to leave the unit and go all the way down to the basement to deliver the samples. Therefore, the route is always the same, always 510 meters every morning very early, because it goes up to the 1, 2, 3 units and down again. And on weekends that's all it does. During the week it's a bit different, depending on how much there is to do. Some send it away a lot, some not as often. And then there's a flow master up in the outpatient clinic, that person is responsible for making sure it gets filled and sent away. So it changes, who is the flow master - they put a sign on the door. So people know who to go to, there's always someone from the staff you can ask for advice."

We look at the screen and talk about what we see. "Look, all these colours, for example, the pink, it's colours that are used for programming. It's zone divisions. The red line here ... The robot MUST NOT go over the red line. The light blue means that only one robot can be in that zone - see now they're sending it away again. But it's because this robot also comes to deliver samples to another point. And we don't want two robots in the same zone at the same time, because then we get a deadlock, that is, they can't get past each other. So they wait outside the zone, until they can drive. And one robot can drive when the other robot is gone from the zone. Now, they've emptied it and they're sending it to the outpatient department, now it's completely ready to receive samples." "What's behind the red lines?" "Well, if I don't want it to drive on this hallway, or if there's a table there, for example, if it can't see it, it'll hit it... So I've put in the red, it's a boundary, that way. So you keep the robot where you want it. You can put in some favourite lines and say, you can drive all you want on this line - and other places on the hallway, we have right-left driving, that is, it always stays on the right side, depending on which way it's driving... Look, it opened a door! It does that itself." "What happens if something gets in the way of the robot when it's driving in the pre-coded path?"

"Yes, it just calculates a new route, because it can immediately see that it can't, what should I do? So it just makes a new route, around what was originally planned. So it stands still, thinks for a moment, and then says okay, well then I'll just drive around. And that's why it's an AMR and not an AGV. AMRs are a little more intelligent and autonomous, AGVs just drive and if something is in front of them, they just stop. And then they wait for it to move and then drive on again. To avoid confusion, some people just call it AGV, all of it. Look, now it's back in the elevator again. And we are so lucky that it's only the staff that uses this elevator. It's a little spicier when you also have to get patients into it, because “what the hell is it doing now?”, they get in the way, don't give space to it - but the staff is used to it, so they know how to act with respect to the robot. Should we pour some coffee?"

We talk about where I have been on fieldwork before - including SHS, where the robots run in the basement and the challenges the robots there have. For example, that they cannot pass by cardboard boxes or other "obstacles" on the corridors: "If you let the robot be too smart and let it drive around obstacles, you may just get other problems when you have narrow corridors. Because then it drives around something and if someone comes towards it, it stops. So it blocks everything. If it stops, then everything stops. And that's what I quickly saw when we had to do these tests in the tunnel. Yeah, you can make them drive, but it would just cause problems. So I quickly said, No, we don't want that, it doesn't work. So we stopped there, we didn't start. The problem with the MiR robots is that you have to have someone on site who can take care of it as soon as there is something. Otherwise, it becomes something like Oh, it doesn't work, it doesn't work, now it's standing still for an hour or something, you have to call an external person. And you don't want that, so you just let it stand and do things yourself - or don't do them. You have to dedicate a person on site to it, who has it as a task and who takes it seriously. I have a rule of thumb: within 5 minutes, I should be fixing it. And I do. As a rule, they don't even notice that something was wrong. The robot sends me a text message and an email, it also does that to two of my colleagues. So if I don't react to it, they do. And we can always access them from the phone, no matter where we are in the world; as long as we have internet."

"What is the purple on the screen?", I ask. "It's one of the most difficult places on the whole OUH; the west wing, near the main entrance. There are patients, relatives, taxi drivers, staff, everything. Patients are standing there waiting to be called in and have blood tests taken. And the red is chairs, tables, there are chairs outside each cabin where people can sit and wait." "How do they react to the robot?" "Well, they smile, laugh, some take out their phone and record a video and take pictures - it actually provides some entertainment."

Esben shows me that he can control the robot through his screen, using a digital joystick. He can also set missions - he asks the robot to drive to a robot stop and shows me the route on the screen. He can see if something is in front of it or similar, "So in 95% of cases, I just take out my phone and take care of what needs to be done. It's smart. As long as there is internet, it works. Sometimes, when I'm sitting in Italy, they call and ask for help to get the robot working. And it's cool! And it also means that our downtime is much less, because I can always reach it. Um.. Yes. And then they have logs, so I can go in and see everything. All the missions that have been put in the queue. Here you can see, the last mission took 6 minutes, that's what we just sat and watched, it was running in the Ambulatory Department from the lab.. Then I can go in and unfold the mission. If there's something wrong, I can go in and see what's wrong. But as you can see here; first it got the mission, then it calculated if it had enough battery, then it accepted the mission. And I've set it so that if the robot has less than 30% power, it will automatically go to charge. The charging stations are in the lab. During a workday from 7-4, it needs about 10 minutes of charging and then it can run all day. The control panels, dashboards, etc.

The phones on the robots, I have customised the functions on them. So the staff can do what they need to do, no more or less. They can send the robot off via this phone on the robot and they can see where it is - they can also use their computer for it. So they can also see if there is a problem and then they call me. As a rule, I'm already in motion when they call. And that can just be programmed as to what you want it to be able to do." "Has the staff on the departments been trained in how to use the robots?" "Yes, I teach them. But it's so easy, so... So you log in with an IP address D245.022, then they come to a login screen, and I create a login for them and when they use that login, they only have access to what I have said they can have access to. They don't have administrator rights, so they can't ruin anything."

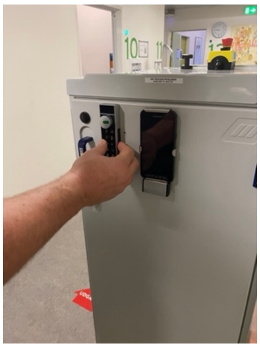
We are looking at the screen while we talk. We are keeping an eye on the robots' movements and after looking at Hubot1 and 2 for a while, Esben looks further to the right on the screen. "The two over next to them, those are our alcohol robots, which are running around with sanitizer. They are over at the Children's Hospital, one here is running - the other is running in the lobby. There it has 8 stopping points. It stands there for 10 minutes at each place and says, 'Step closer and sanitise your hands.' Back when Corona was at its highest, that's where I got the idea. So the idea was up and running, it took 4 days," he says and laughs, while looking proud. "That was quick." "But it also read the Corona guidelines, such as keep your distance and stay home if you're not feeling well and all that. So we got, what do you call it, nudging people in the right direction. And we could see an increase in the number of people sanitising their hands. And people thought it was exciting and fun and oh, how smart. And then we just let one run. It's not that pretty, but... Now we're actually rebuilding it, running over at the children's hospital. It has drawings and stuff on it now, but we're building a box on top, like a house, like a hospital, with windows and light inside the windows, so it's a bit fun. And still sanitising stations on it. The one running around in the lobby, I don't quite know what we're going to do with. Actually, I was contacted by Rosengårdscenteret who asked if I couldn't make a robot for them... I can't do that when I work here at the hospital. So I sent them on to a company that works with these and now two are running around out there in the center." We talk a bit about the company, their robots - and about a mutual acquaintance who works there. That leads us to LinkedIn where we connect and talk about mutual acquaintances in the robot industry, while scrolling LinkedIn and talk about UVD robots.

” We are trying to get started with some testing of the disinfection robot, but there have been some problems with it. There were problems with the mechanics, and it broke down a lot. And then, when you need to get patients out of the room to disinfect it, it can be difficult. Especially when patients are not feeling well after chemotherapy and it's not easy to get them out of the room. Also, in two-bed rooms, you need to get two patients out. But at the new OUH hospital, it will make more sense because we will have 800 single-bed rooms. So, when one patient leaves, we can disinfect the room and the next patient can come in. But for now, we're waiting to test it more.

Esben suggests that we go for a walk and hands me a lab coat, telling me the code to lock the door. I comment on the smell of the lab coat and Esben says it's completely clean. He jokes that I can go anywhere now that I look like a doctor, but I express my concern that someone might ask me for help. Esben says to just say something, and laughs.

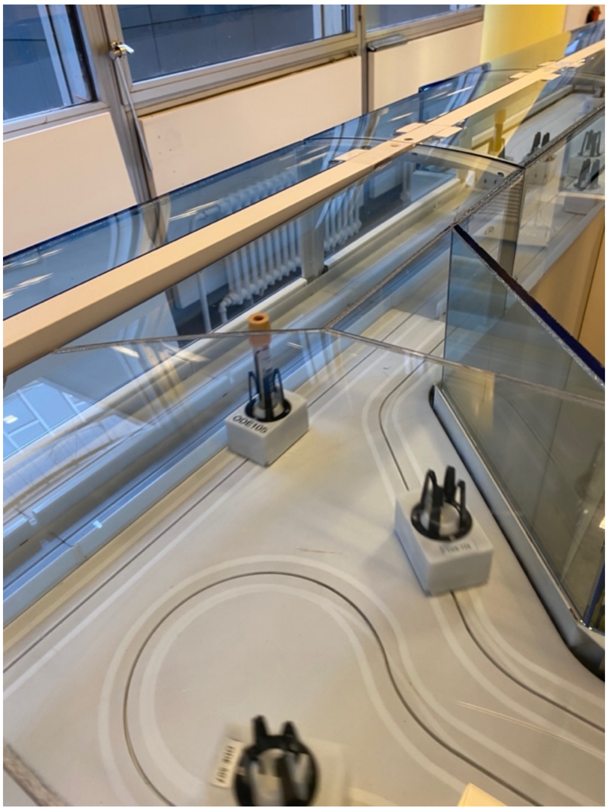
"Esben and I are moving on - up to the Outpatient Clinic to look at robots. My sense of direction is overworked, and I find it difficult to navigate, while Esben moves around comfortably, makes calls and talks and points nonstop. And then he points to a sign with a robot that says, "Here I am", a sign that advises people in the hallway that there are robots among them. It's been here since Hubot came. We walk around the clinics and the laboratory where the robots run and greet the staff, so they know who I am, who will be around the staff and robots. "Hello, we're just looking in, we have Kristina here visiting, she observes the robots - and their use." We talk to a woman in Clinical Genetics Outpatient Clinic and Esben asks, "Are you the flow master for the robot today?" "Well, we could say that I am." Maybe it's a role they don't take too seriously.

And then I spot it: Hubot. A mobile robot with a hospital cabinet on it, labelled HUBOT, a large emergency stop button, a smartphone attached, a lock and an antenna. Esben opens the cabinet door and shows me the drawers inside. A woman puts blood samples into Hubot's drawers, closes and locks the cabinet door, sends the robot on its way via the smartphone screen - and we're off, we follow after Hubot."



We continue on,
Esben explains how the robots can open doors on their own, tells us where the robots are operating, and we move on. There are plenty of people in the hallway and Esben explains how it's important that the robots are programmed to take into consideration, implying that they are not in the way of people. And it seems that people in the hallways find the robots amusing rather than annoying. Esben tells me that when the robots need to use the elevator, which they share with staff, they go to the front of the elevator and wait until there has been no activity for 15 seconds. Only then does the robot take control of the elevator. It turns out later that the robots can risk waiting a long time for the elevator because the staff frequently use them. And since the robots are programmed not to be in the same zone around the elevator, there is a risk that one robot will stand for a long time in the hallway waiting for the other robot to enter the elevator and thus continue on its way.
When a robot is running from the hallway to the outpatient clinic to get to an elevator, it also asks the control system if there is already a robot in the elevator - if no, it goes in. Otherwise, it waits outside the zone. When a robot has taken control of the elevator, a person cannot control the elevator. They have to wait. We go into the staff hallway and see a sign hanging on the wall explaining that the robot must use the elevator. Staff can certainly take the elevator with the robot; they just shouldn't stand too close to the robot. "You can see on the floor where the robot usually stands. You shouldn't stand there. Someone has crossed out that you can ride with the robots, but you can. The problem is that if you are standing there when it needs to get out, it can't get out." The robot opens the elevator, turns around and goes out, now we're on our way to the

laboratory. Hubot goes into the laboratory, goes to its stop in front of "Projects", plays a sound and thus advises the staff that the samples for them have arrived. A bioanalytical chemist comes out and empties Hubot of samples for her. She can see that there are also samples in Hubot's other drawers - and therefore sends Hubot on, so it can deliver these, in the right place - in this case, it is another place in the laboratory, where the samples go into OUH's blood sample automation and are sorted and analysed. When Hubot is empty, the staff sends it back to the department it came from."



"Esben shows me the blood sample automation, the Blood Sample Robot, and tells me that when the blood samples are to be put into it, after they are taken out of Hubot, the staff goes over and puts the samples in there. He adds that the samples that come with tube mail also save the staff from going the 3-400 meters that are - and then the samples go into the blood sample robot, where a robot arm picks up the sample, scans the barcode on it, puts the sample on a "car" and now that car knows that Peter's blood sample is to be analysed for this and this and this. We have 10 of them. Here you can see the highway, otherwise they just go down and then to the machine they now have to go to. Then the lid is taken off. It handles and analyses 8000 blood samples per day. That's a lot! Down at the bottom of the room here, you can see a blue refrigerator. Inside, there is room for 10,000 samples. They are then stored inside for a week, so the doctor can request another analysis of the same sample. After 7 days, there is such a robot arm that takes the one-week-old sample, throws it into a pipe that leads down to a container - and then it is taken to the incineration twice a week.

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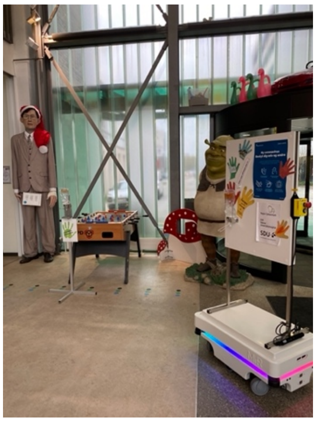
See, now Hubot2 came over from the Children's Hospital. Now she's emptying it," says Esben and points to a woman in a lab coat, "Now it's empty - now she's sending it back to the Children's Hospital." We walk over and look at Hubot2 before it drives away. Esben stops it so it doesn't drive away from us and a woman from the staff reacts promptly to Hubot2 not driving. "Didn't he react to me?" she asks wondering. Esben says "Yeah, yeah, it was me who emergency stopped it." Hubot2 is a MiR-robot with a white box, with a door on top. Attached with a smartphone, an electronic lock and an emergency stop button. "All this, it's something I built and made. Underneath the lid here, there is a hollow space. I inserted a box like this, for 40 DKR from Jysk in there. It's one-piece, meaning it's easy to clean. Down in the box, under the hollow space, there is a lot of mechanics. Up here on top is a lock, the code is always 1646 - and then there is the emergency stop.

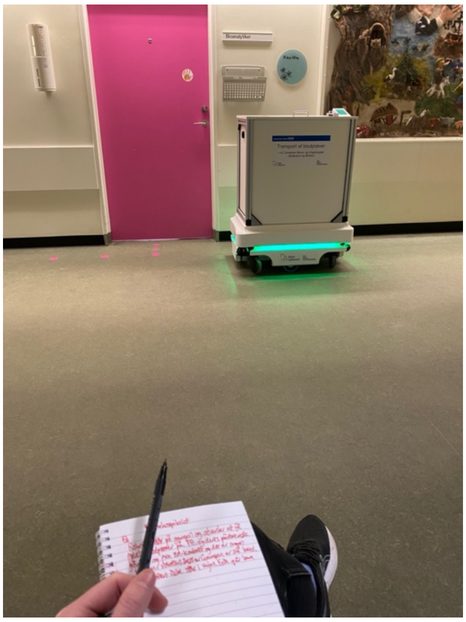
"We follow Hubot2 up to the Children's Hospital. I notice how wide the hallways of the hospital are - they are geared towards robot traffic. The robots run on the ground floor, on the 1st floor - but not in the basement, because there is not enough space; the hallways are too narrow and there has to be room for trucks. Esben tells me how Hubot2 in some cases, for example when it needs to use the elevator, scans the room around it - and then a blue dot appears on the floor. He also tells me when I ask about the thoughts behind the robot's appearance, that Hubot1 consists of a cabinet he found in a basement - and since the budget is not endless, he has built Hubot2 with cheap materials and something he already had. A cabinet similar to what Hubot1 consists of costs around 10,000 crowns - and what is on Hubot1, was put far away in a remote corner of the hospital and was not used."

Hubot2 has been running on the hospital for 3-4 weeks, Esben tells me. It runs between the laboratory and the Children's Hospital. We are still following it. On its way from the laboratory, after a short walk, Hubot2 takes the elevator, goes to the Clinical Genetics Department, then out to a large hallway, out to the lobby (where it plays a ringing sound to warn the surroundings. Hubot2 also changes maps briefly when it enters the lobby. It runs on 4 different maps: the basement, 2 over the ground floor and 1 over the first floor. Hubot2 calculates its route and then continues past the elevator junction, where there can be many people, Hubot2 says "Please step aside" in a calm pace when it runs in the lobby. It passes by one of Esben's hand sanitizer robots, which stands and blinks in the lobby. Hubot1 and Hubot2 are programmed not to run close to chairs and elevators. From the elevators, Hubot2 goes down a long hallway, after which it arrives at its destination. "But this is so easy. It just takes care of itself. Sometimes the elevator can be a problem, it can sometimes get stuck. But I get notified right away and fix it." We go down to the Children's Hospital and Hubot2 plays an arrival sound, so the staff knows that Hubot2 has arrived and is ready to receive samples. Esben takes me to another hallway in the Children's Hospital and shows me the sanitizer robot that is placed here. "It just runs back and forth here," he says and tells me again about how they plan to redesign its appearance to look like a hospital.



”Basically, it's clear that Hubot is doing most of the work," he says - and then we move on. Esben shows me where the kiosk, canteen, etc. are, and we agree that I can just call if something comes up - otherwise, I'll just manage on my own. Esben tells me where Hubot1 and Hubot2 are now - and then I can find them myself. "Just call if there's anything," says Esben before waving and leaving. I'm standing in the middle of a long corridor in an out-patient department without any people. I try to orient myself, think back to where we came from, where we've been. But it's a bit difficult for me to find my way around the hospital. Already I'm bad at finding my way around, but when we followed Hubot, my focus was on the robots, the conversation, the surroundings - not at all on the routes or the logic thereof. This results in me walking around confused on the corridors, up the stairs - and trying to find a robot. An employee asks me if I need help. I tell him that I'm looking for a robot. "A robot?" "Yes, Hubot1 or Hubot2.
"Do you know anything about them?" "Umm, yeah those that come rolling down the hallway, sometimes? It might be here, it might not be, but it could also be in the out-patient department or in the basement..." "If I want to go to the out-patient department, which way should I go?" "You have to go out of the red door and then turn right. But like, he could also be in the basement?" "Yes..." "I don't really know where he is now.." "No, me neither... I'll try the out-patient department first and then check the basement afterwards. Thank you so much for your help!" "Can't you call the one who controls him?" "Yes, I definitely will if I don't find them in the out-patient department or the basement." "Have you looked in the basement?" "No. Not yet." "Oh. Okay. Okay okay." "I'll check the out-patient department first, then the basement." "Okay. Well then you just have to turn right down there." he says, pointing towards the end of the hallway. I continue on, trying to find a robot. I can't find any out-patient department at the end of the hallway, but I've somehow ended up on a hallway with a sign that says "Foyer" - and from there I know how to get down to the Children's Hospital. So that's where I head - and when I get there, Hubot2 is outside the bioanalytical lab - where children have their blood tests taken.

It is now 9:30 AM and I have been at the hospital for an hour and a half. I sit on a chair in the hallway and observe as the bio analysts, the two that are in the office, take one child after the other in for blood tests. The robot is standing in the hallway and its light is green, indicating that it is waiting for a mission. Nobody is reacting to it; it stands unnoticed and undisturbed.



One of the 12 children notices the robot and says, "Look Dad, that's a robot" "Yes, it's cool, don't you think?" the father replies and the child say "Yeah”, and they walk away. There is still no staff that has interacted with Hubot2, now 25 minutes have passed. The hospital hallway is so wide that Hubot2 is not in the way, there is plenty of space and people just walk past it. As another patient and their parents exit the pink door, I see my chance to greet the bioanalysis inside. I knock, greet them and say that I am here to see the robot, maybe Esben has warned them, I joke. They apparently haven't heard anything, but they are happy that I introduce myself as they had wondered who was sitting in a lab coat and taking notes in the hallway in front of their office. "You're just in time," one of them says, "I'm just about to fill samples on Little Hubot!"

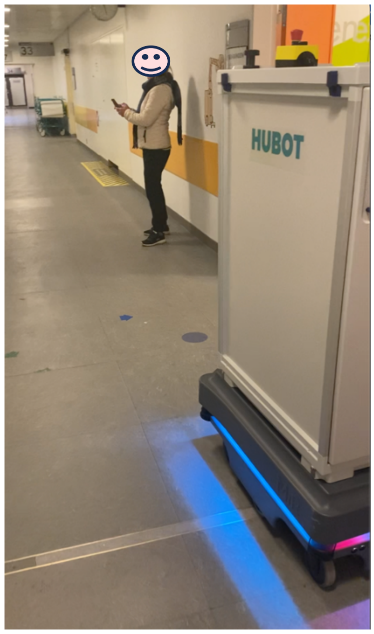
A woman comes out of the office with a rack, a blood test stand, which she sets down in the drawer of Hubot2 after unlocking the robot. She closes the door and tries to lock it, but it's difficult for her to do so. She says, "I don't think my hands have the right magic touch." She enters the code again and again, but the lock keeps flashing red. She says "I also struggled with it the other day. He doesn't want to cooperate with me." She calls a colleague from inside the office "Can you try with your fingers? Because he gets angry every time!" The colleague asks, "Did you open it?" "Yes, I'm going to send it away" "What about the code?" "No, it's not that." "Yes, just enter it like this" "No, you can see it's not that, because it's flashing red. It's not accepting it; you can't do it." They try entering the code many times and the robot's lock still flashes red. "That's how we were with it the other day." "The code is 1646 and sometimes it's so dumb because you have to press so hard and precisely. Look, it just turns red! But I've been told sometimes we're not pressing hard enough! But look, now we're pressing extra hard, like this." They finally succeed in locking the robot, and it can continue its mission. She enters a mission (telling Hubot2 where to go) and sends it off, but it doesn't move. "Why isn't it moving?" She enters the mission again and says "Ok, now it's sent to the basement, have a good trip" and pats the robot before going back into the office and closing the door. Hubot2 remains standing. After a couple of minutes, the person observing intervenes by checking their smartphone to see if the mission was entered. The bioanalytical woman did not press hard enough so she thought she sent the robot off, but it hadn't actually been sent. They thought the robot had been sent, but it was just standing there. So the observer sends Hubot2 off and it moves. They were unsure if they should intervene, but they didn't want to disrupt their work or slow them down and make the sick children in the waiting room wait longer because of them. So they press the button on Hubot2, and no one notices, the tests come through, patients come, and everything goes as planned without delays.

I am following Hubot2 as it moves on the hallway. It moves slowly, safely and directly into a hand sanitizer stand that is on the hallway. Hubot does not notice it but continues. It is later revealed, when I bring it to Esben's attention, that the stand has such low feet that the robot's sensors cannot detect them. But when I bring this problem to his attention, he immediately goes out and locates the stands and goes into programming the Hubots to avoid the hand sanitizer stands on the robot routes. "It's because the scanner it has, it's located in the corner, it makes the robots only see what's in front of them. So if it's on the side, it might run into it. But that's not good enough! So I need to fix that and do something about it. Now." So we cross our fingers that no one moves the stands.

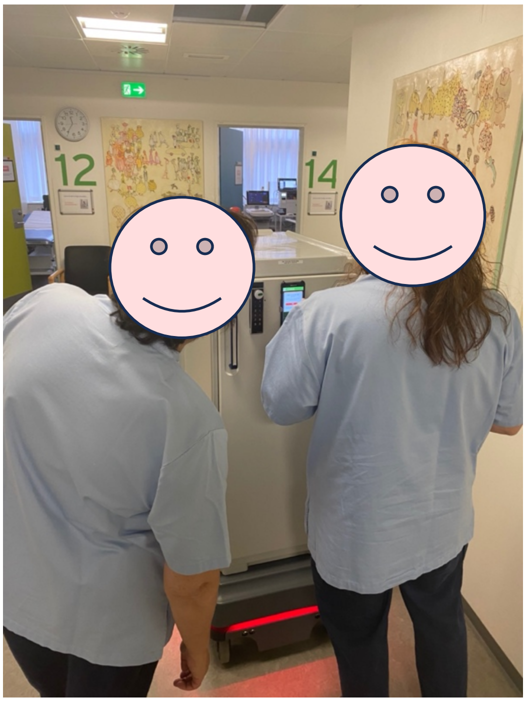
Hubot2 leaves the Children's Hospital and passes a main entrance with mixed traffic. Behind a couple who are standing and pulling out candy and soda from a vending machine - they don't even see the robot; they don't react to it. The hospital staff doesn't react either, they are apparently very used to sharing the hallway with robots.

It is 10:06 and I am following Hubot2. It primarily drives on the right side of the hallway. Patients and relatives smile at it and describe the robot as fun, a smart addition. "Oh, what's it doing there?" says an older woman in a wheelchair, as Hubot2 stops right behind her. When I overhear what people at the hospital say about the robots, they are generally very positive and describe them as a fun addition to a serious reality. Patients and relatives notice the robots and pay attention to them, as they drive where patients and relatives are - in an environment with multiple different types of traffic.

Hubot2 goes around the woman, beeps with a bell sound to warn, now it needs to cross the hallway, to get to the outpatient clinic and then continue downstairs to the laboratory. In the outpatient clinic, this time, I only see a cleaning lady - and I will meet her many times, she greets me every time I pass by, also says "hello" to the robots. Hubot2 takes the elevator down. When it enters the elevator, it drives forward - so when it needs to exit, it uses time to turn around, only when the elevator arrives at the correct floor and the doors open. Some employees expressed frustration that the robot does not use the time while the elevator is running to turn around. In that way, time could be saved, which is valuable when personnel and robots share the elevator. We come down to the laboratory, Hubot2 and I. Hubot2 goes to its spot, plays a sound, no one immediately reacts to the arrival. Hubot2 waits for a couple of minutes. An employee goes to Hubot2, takes the samples from the Children's Hospital and sends Hubot2 back. He is holding the blood samples - and sorts them by hand. He tells me that not all types of samples can be handled by automation. We are interrupted by a "Oh" because Hubot2 has stopped. A bioanalyst quickly walked in front of it and it is programmed to immediately stop. "Yes, Hubot and Little Hubot never drive into us... It's more us who can accidentally bump into it, because we don't notice that they are here," says the employee who was explaining to me about blood sample sorting. And that seems to be the general attitude among the staff who share the work environment with the Hubots. However, patients and relatives are more cautious and hold back for the robots, move for them and keep an eye out for them. For example, I am repeatedly witnessing the Hubots driving very close to people in the halls, causing people to stand against the wall to avoid being hit.



I am following Hubot2, we are going back to the Children's Hospital again. We wait again for a while before Hubot2 is filled with samples, but this time there are no problems with sending it off. We come down to the laboratory, the robot plays its sound, and an employee comes and empties the box in Hubot. I am again following Hubot2 into the outpatient department, back to the Children's Hospital. On the way, we are met by Hubot, which is bringing samples to the Outpatient Department. "Samples have arrived, samples have arrived." Then nothing more happens. The cleaning woman apologetically looks at me and says "Yes, maybe they went to lunch..?" She looks for someone who can take care of Hubot, she finds someone who comes over, empties Hubot of samples and says "Thanks, Hubot - yes, he is very cooperative." and walks away. And the cleaning woman says "Yes, but we have to keep an eye on him and help him all the time." And it seems as if she often advises the staff that Hubot has arrived. As she says that, another female employee walks by and says "Yes, but he is a man, yes!" in a ringing Danish accent, while laughing. And then Hubot continues with samples, down to the laboratory, because the staff who sent Hubot off in the first place made the outpatient department as a single stop on Hubot's route - and added the laboratory as the next stop. But something apparently went wrong, because Hubot is not going down to the laboratory, but over to the blood sample collection, where it had just come from. Now it stays there and announces its arrival. The staff becomes very surprised and says that the error is with the staff in the outpatient department, who pressed "Basement" instead of "Continue mission", while those in the Outpatient Department told me that they pressed "Continue mission". "Yes, but that's because we only sent it down to Genetics (outpatient department). Normally we should send it to Genetics and then on to the Lab. And that's gone wrong here. For then it would have continued. But now I'll send it down to the Lab. and then come back up again after."



As I follow the robots, I am sometimes asked by random people on the hallway if I am training "them", if it is me who controls the robots - and an older woman who is a volunteer guide at the hospital finds it extremely funny that I am following the robots with a serious face. She is in a spot where the robots often pass by and almost every time I pass by, she laughs at me. One of the times she asks me "Are you sure you shouldn't get a real job?".

Hubot and I come again to the Blood Sampling - and here a BA (BA1) has challenges with unlocking Hubot. "It's like it's completely locked?" says BA1 and tries again and again. The code is correct, but Hubot's door remains closed. She gets assistance from a colleague, BA2. "What have you tried?" "Nothing," she says almost apologetically. "I just have to open it." "Oh, you have to open it?!" Suddenly Hubot drives off and BA2 exclaims "So for Satan!!" and hits the emergency stop button. They try together to enter the code again and again and again, without success. I ask what they are doing and BA2 says "Well, I can't tell you what I'm doing now - I'm just trying out some different things." BA1 stands a little behind BA2 and says repeatedly "It's a bit like, what it is, it's that it's locked." "Oh," sighs BA2, "Well, then we have to get a hold of Esben." and then she calls him. While she is calling, BA1 tries to open Hubot's door by giving it a hard hit. When that does not work, she makes resigned arm movements and walks away from the robot in defeat. BA2 calls Esben, "You know what, I'm here with Hubot and he just won't open up. Now he won't even let me do anything... It's like the lock, it's supposed to go to the right side to be unlocked, but it's already there and he still won't open up.." Esben gives her a reset code which she enters 52020 and the door opens. Thank you, that's all. "She tells me that she did not know that such a smart code existed for "something like this." BA2 calls BA1 back "What's up? Were you supposed to send something down?" "I have something down to Projects, that needs to be sent!" I ask

I ask them what Hubot is carrying versus what is being carried by service workers and BA2 responds "There are some things that are being carried by KMA and KIA, right, and then there's something for Pathology, for example - isn't that right?", she asks BA1 who supplements with "Yeah and if we have something on ice or if something needs to go quickly, we send it with service. Because we don't know where it ends up," she says and nods towards Hubot "So we risk the samples getting there too late." I ask about what can happen since they don't know where Hubot ends up: BA2: "Sometimes he goes somewhere else." BA1: "He'd also gone upstairs, right?" "BA2: "No, he doesn't do that." BA1: "..." BA2: "Yeah, sometimes he takes the elevator the wrong way and then he's suddenly somewhere and just standing there." "How do you find them the robots, then?" BA2: "Esben can. There are some people downstairs who have a program where they can see where the robots are. You can go in and see where Hubot is. So you can see where he ended up."

I ask the same question to a BA in Projects (down in the Laboratory), and she says that they themselves must transport samples when the robots charge. "How often does it charge?" I ask, to which the BA replies, "It charges once a day. And then it charges at night. It also depends on how much they send down. If there is a lot that needs to go down, then it will quickly run out of power." I ask if there are any sample types that cannot/should not/must not be transported with robots, and she replies: "It's very rare that it's necessary. As a rule, they can send it down if there's something urgent. So no, there aren't really any specific types of samples we MUST go with. But if, for example, he (points to Hubot) is standing and charging and there are some urgent samples for Projects, then we do. Otherwise, we get the clinic to send them, with a service." It occurs to me that my question was too vaguely formulated, I should not have asked if there were cases where "you yourself" transport samples, but asked if there were cases where human personnel, rather than robots, were preferred sample carriers. I try to save it by asking about how it works in those cases: "So they order over a program on the computer and then they come down to our reception with the samples." "Are there any things that can go wrong when robots have to transport something?" "Well, sometimes he gets stuck in the elevator. But then we call Esben, and he is here right away." "It's good that you have him." "Yes. And if he's not here, then one of the other two is here fortunately.""

Out on the hallway, in one of the areas with a lot of traffic, an older woman sits in a wheelchair, her daughter standing behind her. The wheelchair is just barely within a yellow marking on the floor and now Hubot is coming towards them. "Mom, I'll just pull you back a bit," says the daughter, "so you don't get your feet run over by the robot." "Oh, no don't bother. He knows me! He knows that I sit here and that he shouldn't run into me. We've agreed on that," says the older woman. She is clearly a patient who has been here before and is used to the robots. The daughter looks at me and says "Yes, at first I thought it was running with sandwiches, but..." The older woman interrupts and says "NO, it runs with blood samples!" "Yes, my mom has told me that it runs with blood samples, it's just so smart. But sandwiches would have been a good idea too."

I come across the flow master of the day in the Ambulatory department together with Hubot and I talk to her about how she and her colleagues experience having Hubot running around: "I think it works fine. There are practically no problems. Or, well, there are just sometimes something around the elevator, but I don't think it's a big problem." Hubot starts running and she says "Well, you better go after him."

Back in the laboratory with Hubot, which comes with samples. In the laboratory, Little Hubot is standing, and I decide to focus on it. A BA comes over to empty Hubot2 but has problems with the lock. "Yes, it has just been changed and the others say that it works much better now, but I still think it's very difficult to press down on. Big Hubot, he is much easier to deal with than Little Hubot!", I ask what they did before they got Hubots and the BA tells me, "Over at H-Amb (blood collection), they sent service assistants over with it if they didn't have time to go over with it. So we've saved a lot of manpower and time." "What does it mean for you here, that there is a robot here, with you?" "There's not much difference for us here in the laboratory. Before we got it through our hatch, now we take it out of Hubot." I ask what she thinks about Hubot2's appearance: "Now we've been used to Big Hubot, and I think it's brilliant that you can save either a BA or a service assistant, so there's no longer anyone who has to spend time and energy on carrying samples. But sometimes they can go a little out of control near our elevator - but then we have our Esben, so we just call him, and it all works again."

At times, I sit on the corridors and observe how the staff interacts with the Hubots. Most often, a Hubot is standing unnoticed on the corridor and waiting for emptying and refilling. The staff is so used to the robots that they don't notice them. Most people call Hubot "he".

On the corridor at Blood samples I sit and watch, a female BA comes, fills samples in Hubot and loudly exclaims: "ANYONE HAVE SOMETHING FOR HUBOT?!!!", "NO!" comes back. She sends Hubot on and it drives away. Hubot drives out on the corridor, stops because a patient quickly goes in front of it. People look at it, smile at it and talk about Hubot. They see it as a bit of a fun gimmick, I can hear. "Is that you controlling it?", I am often asked, when I walk around behind the Hubots. "OH!", exclaims a woman, on the corridor, as Hubot comes towards her. A little boy follows after Hubot, he thinks it's cool, he says to his parents. "Just look, mom, it just drives all by itself, like this!", Old lady drives a wheelchair into Hubot. Hubots really function as a means of transport here at the hospital and they save the staff from walking around with samples and they also save time..

I go down to Esben's lair and we have a chat about the robots. He tells me that the lock is a type of lock that is used in swimming pools, in the lockers in the changing rooms. He offers Quality Street candies, and we find out that we have the same favourite there- so he regrets his generosity, he says. I tell him about some of the observations I have made. About Esben's responsibility and the elevator challenges that stem from there not being WIFI access points in the elevator, so the robots lose connection to the network when they're in the elevator. Sometimes it can go wrong 4 times a day, other times it can go three weeks before the problem occurs. I tell him that the staff hardly notices the robots - and he says that there are no problems, because they have good space. He thinks it was a good idea to let them drive with sandwiches. Or apple fritters in a warming cabinet, leading up to Christmas. I tell him about my other insights from other hospitals and he tells me about other robot projects they have attempted. Esben leaves and I look around in the lair and gather today's impressions.

DAY 2

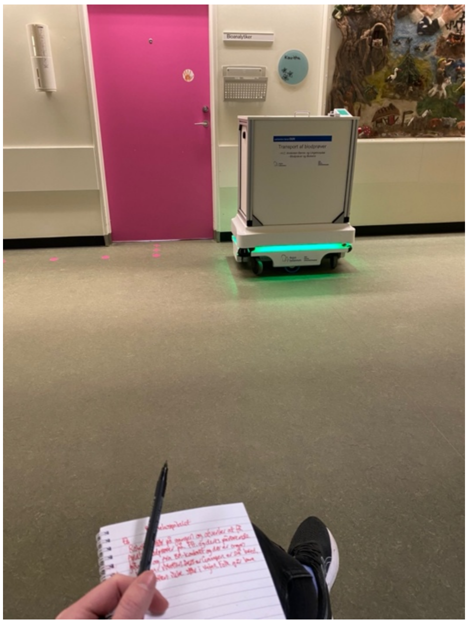
On the second day, I arrive at 7:30 and find Esben in his lair/cave. He offers me coffee and while we drink it, he shows me a lot of pictures and videos of robots that he and colleagues from OUH (Odense University Hospital) and SDU (University of Southern Denmark) are involved in, in one way or another. "We have released 12 man-hours a day by using this," he tells me about a tissue sorting robot that they are currently implementing. He explains how the employees have been testing the solution with the suppliers and I get a sense that technology development based on needs is very important to him. He shows me a large and very comprehensive excel sheet with needs, solutions, technologies, users, and companies that they use to come up with new projects. Sometimes actors also come to them and approach them. Suddenly, he interrupts himself and says "Oh, you have to SEE something cool!" He shows me, very proud, a clip from the TV2 news about the hand sanitizer robot that runs around the OUH. They talk about an electrician who built a hand sanitizer robot in the fight against corona, and he smiles and says "That was me! I was on the 19 o'clock news, dude! Haha! That was when corona was at its highest and everyone was at home watching the news! Mega cool!" I tell him that I had seen it when my Odense-based father-in-law always tips me when robots are in the media. So he looks very proud too. We talk about robot technologies and suddenly Esben's phone rings several times; it's an alarm, one of the robots has stopped in the elevator. "Unable to find path," it says - so now it needs troubleshooting! The robot thinks it's in the lounge, but it's not sure it is, he says, because when it's in the elevator, it can lose the card. Esben takes control of the elevator, drives it to the lounge. So he knows where it is. The elevator door opens, so the robot can drive out, but it closes quickly - and it must not happen, because the robot might crash into it, he says. He opens the door again and checks the cards. The door remains open, Esben sends the robot out of the elevator, he releases the elevator control and then he checks the log of what it was doing. He sets that mission back in motion and then things run again. "And I don't even have to go up there, isn't that great? I can just sit here and eat candy!" I say goodbye to Esben and go on a Hubot hunt.

In the morning at the lab, I went to the section of the lab where the bio analysts sit and work. I approached one bio analyst, BA3, and asked her what she thinks about working with a robot. "I think it's fine, it means the samples can get down much faster," she said. "So you save some time?" "It doesn't make a difference in time for us, whether the samples come in the slot or with him, it's the same," she said. "Is there still something that comes in the

slot?" "What comes from the departments and such. But before, they came from the Children's Hospital too." "Okay. How can it be that it's just the samples from the Children's Hospital that must be run with Hubot?" "I think it's because they want faster answers," she said. "Okay, so it goes faster with Hubot?" "I think so, otherwise it's Service that has to go with them - but they're already busy enough. And since it's just a "from A to B" task, I think Hubot is smarter. It could be smart if you had a Hubot on all departments, because I think if Hubot had to run from department to department, it would be logistically hopeless." I asked her if she perceives Hubots as colleagues, tools or something else and she said: "I think it's a tool! But on the other hand, we also talk to it as if it were a person." "Do you? What could it be that you say to it?" "If now for example, both robots are standing here and they can't decide who should go first - or if you've accidentally sent it off before you've put in new racks - then it becomes something like Hoovhoovhoovhoov, no stop, MiniHubot, wait for me!" I asked if there's anything that irritates her about the robots and she said: "Not really, I mean.. MiniHubot. When we must enter the code, MiniHubot doesn't always understand that. The buttons are hopeless." "Do you have any concerns about having robots running here?" "No." "Do you think it disturbs you? Does it interrupt you when it arrives and needs to be emptied/filled?" "No, I mean, I think we're good here, if we're busy and don't have time to empty it, it'll just have to wait. But otherwise, aaayyyy.." "Does it do anything if it stands and isn't emptied?" "I know the big Hubot, it comes with such a boat horn if it's been standing for a while.." One of her colleagues, BA4, chimed in and added that the robots have made their work more efficient, but it's not always easy to understand the robots.

One of her colleagues, BA4, chimes in from where he's sitting, "I also think I've heard little Hubot say all sorts of strange things?" "Have you heard it say anything strange?" "Yes, I can't remember if it was the "R2-D2" sound from Star Wars, I think it was - it was crazy!" "When can it be that it says that?" "I don't know, I think maybe it's if it has been standing for too long or something." "Is there something that irritates you about them, or is there something about them that has a special impact on your work? Something you think is extra good, positive, or…?" BA3: "Well, it's a good tool." BA4: "Yes." Me: "And it just works?" BA3: "I think so, yes. I mean, there have been rare occasions when the other Hubot has been stuck in an elevator, or someone has... Especially if there have been beds on the hallway, he can't see them very well. So he gets stuck a bit. It has happened a few times. So you can see, it's not very good." "Do you get notified, or is it only Es-ben?" "Well, if it's during the day, I don't think we notice it. We had a time when Hubot was running on Intensive care in the morning and then the night shift said it hadn't arrived. And then we could see that it was because it was standing on the hallway and was blocked." "So there was something that prevented it from getting by?" "Yes, it was a bed." "The ones who put the bed there, is it because they aren't aware that the robot should run there?" "Yes, and maybe they think it can run around it. But it can't. But it's been a long time since then. But that's the only thing."

I find another BA worker in the laboratory (BA5) and ask if I may interrupt her for 2 seconds. "Sure, what's up?" I ask her what she thinks about working with a robot. "I like working with robots, I've been doing it for over a year before I came here. So that's.." "May I ask how you worked with robots before?" "I worked with Hamilton (liquid handling robot) at XX in Copen-hagen." "So you're used to robots!" "Yes, they don't bother me. I mean, it was the first time I worked with robots, now I'm doing it again." "What do you think when you hear a noisy ro-bot?" "A tool. I mean Hubot is a tool, so we don't have to go up and down all the time to find samples. And it's the same with that (points to pipetting robot) it's also a tool so we don't have to pipette so much by hand. So we don't get wear and tear." "Okay. How long have you had Lit-tle Hubot here?" "It's really, really new. It came after I arrived. And I arrived on January 1st this year, so that's it." "Okay. And the old Hubot has been running here for..?" "I don't know." "Do you experience any difference in how they run?" "Well, we don't have much to do with Little Hubot here. It only runs over to Sample Receiving." "So it's only Big Hubot that stays here with you?" "Yes." "Okay. Is there something you think is good about Big Hubot, really an-noying or.. Positive/negative sides of having them?" "The good thing about having Hubot is that it's divided, so you can see where what should go. In the little one, there's only one space. But it makes sense when it only goes to one place." "So it's three different drawers that Hubot has?" "Yes, and then it has the bottom one where we can put the overnight urine, over to the re-ception. Or cryoboxes or.." "Are there times when Hubot doesn't complete the tasks it should?" "Well, the only thing I've experienced is if it gets the elevator to stop working." "So no one is messing with Hubot, for example?" "Yeah, sometimes, if you're standing too close, it won't re-act. That's how it is with robots. Sensors and sensors." "Do you have any concerns about hav-ing robots at work?" "No." Another BA comes in with samples for analysis and makes some mistakes that make me must let go of BA5, but before that I manage to ask her what she thinks of Hubot and working with Hubot: "I think it's really easy! It's straightforward, there's no need to think for a long time." "Does it ever disturb you?" "No, because we can easily let it stand and finish what we're doing - and then go over to empty it." "Okay." "And it only rings once and it stays until it is emptied. It doesn't just start again."



I go to the Children's Hospital and find Hubot2. It is parked outside the BA office, so I sit on the same chair as yesterday and wait for something to happen. A female employee rides past me on a bicycle, stops, and backs up to me. "Are you watching the robot or what? I also saw you down at KBF," she says. I answer yes and she laughs. But in fact, there is a reason she is addressing me, because she wants to ask if I can help her make sure "that one" (the robot) stops tipping over her bicycle. It turns out that she delivers mail on the hospital - and she has experienced a few times that her bicycle has been knocked over and the letters are scattered around the entire hallway when she comes back to it after parking it and going on an errand. When this happens, she goes into the Children's Hospital and asks them to take care of "that one".

I go up to the Children's Hospital and find Hubot2. It is parked outside the BA office, so I sit down on the same chair as yesterday and wait for something to happen. A female employee rides by on a scooter, stops and backs up to me. "Are you keeping an eye on the robot, or what? I also saw you down at KBF," she says. I answer yes and she laughs. But in fact, there is a reason she is addressing me, because she wants to ask if I can help her make sure that "that one" (the robot) stops knocking over her bicycle. It turns out that she delivers mail on the hospital grounds, and she has experienced a couple of times that her bike has been knocked over and the letters are scattered all over the hallway when she returns to it after parking it and going on an errand. When that happens, she goes into the Children's Hospital and asks them to get a handle on "that one." I get her to show me where the bike is parked when it happens, and she tells me that she makes a point of parking as close to the wall as possible so as not to be in the way. The bike is parked right where Hubot2 passes by several times a day and both the woman, and I are therefore sure that it must be Hubot. She tells me that she has eyewitness accounts of the dramatic situation and I promise her that I will do what I can to prevent it from happening again. She is very puzzled about why it is even possible, but she thanks me and rides away. I tell Esben about the episode when I meet him by chance in the hallway and show him pictures, and he is very surprised. "Okay! No, is that right? Has it knocked over the post office bike? No no no, I'll hear something about that soon. Damn. Well, that's new, I've never seen that before. No. It probably just rode by the wheel and couldn't see that footrest, down there. It would be fun to try to recreate that." He had no idea that could happen. He immediately goes down to reprogram Hubot2's path so that it no longer stays so close to the right in that particular area. It turns out that the sensors on the Hubots cannot "see" the bicycle, because the footrests are so low - the same problem as the hand sanitizer stands - and that is why "that one" knocked over the bicycle. "I'll have to go down and fix that," says Esben.

I follow Hubot2 down to the lab, where BA4 is standing, he is about to take the samples out of the robot. "I am asking what he thinks about working with a robot and he answers: "I think it's very fine! It's a good tool, I think. It makes it somewhat easier to get things done around here. It's very easy to use." "What do you think about the Hubots? Do they take up a lot of space here?" "No, they don't take up much space and they're good at manoeuvring around. You quickly get used to them being here, too. At first, I was like, now he's coming here.." he says and moves a little to the side, "and then you had to make room, but they're good at manoeuvring around, I think. I don't experience any big problems. The Hubot never runs into us, it's probably more us running into him, because we didn't see him. It's not him running into us, it's us running into him. He's too polite!" "Now you say him, is it a male?" "It's Hubot, yes. So it gets a personal touch. "What do you actually think of its appearance? And have you considered doing something about it, so it looks like something?" "No, we're not allowed to really do anything to them because of the hygiene nurses. The plan was to have the MiniHubot covered in Lego, that was the plan. But we couldn't do that. So.." "Are there any functions you would like the Hubot to have?" "No. Like, just for Christmas, we usually put a little Christmas figure on it. That's been the case for many years, a bell!" "That's something you should do, it's about time! How can you be sure that the Hubot performs the tasks you send it on?" "Well, sometimes there are problems with the elevator. Sometimes, there are people who don't notice that he's in the elevator. And then they take the elevator with the Hubot, and he ends up on one of the floors where he shouldn't be. So he gets out of the elevator up there and he's confused, the Hubot, because he doesn't know the way up there." "What happens then?" "He just stands still up there until someone calls and tells him he's on the wrong path." I ask about what's positive and negative about using the Hubots and he answers: "It means you don't have to run back and forth. And the genetic tests are easy, because he's going that way anyways, so we can just throw them on there." "So they make many things easier for you?" "Yes. But there are some things the Hubot doesn't carry. We sometimes have some blood samples that need to be done within half an hour, you can't really rely on him to get them done." "How can that be?" "If he's just left and you just took something that can only wait half an hour, you can't expect him to get back and down in that time." "How long does it take from when he leaves here to when he's back again?" "I actually don't know. It doesn't take long for him to drive. But they need time to empty it up there and fill it. So they don't send him right away." "Is there a system for when the Hubots are sent out?" "No. There's someone who has...responsibility for him up there, that's how it's been - but it's usually the person who's supposed to make sure the Hubot gets sent out." "Do you have that here too?" "No. Here it's whoever has their hands free. And it's not like it takes a long time." "So you don't experience him disrupting when he arrives and plays sound?" "If you're standing alone here, yes, it can be a bit disruptive. But it's not always. And the big Hubot, he pushes if he's getting too impatient. So you get a real shock over that." "Do you have any concerns about working with robots?" "No. Not the Hubot." "You don't think robots will come and take your jobs?" "No, no, no, and especially not the Hubot." "Why not?" "Well because he transports things. But now there's this blood sample robot.. But I think most people would be nervous about having to stick their arm into a machine that comes with a needle. I would be too!" "What do you actually think when you hear the word robot?" "I think it's something that takes all the tedious work."

I take the elevator to the ambulatory department with the Hubot. When we get out, a female employee is standing there saying, "He's so SLOW to get out of the elevator! " I inquire about it, and she says that the Hubot is simply a pain to work with because "he" takes the elevator in front of her. She also says that she has experienced many times that the Hubot just stands in the elevator and investigates the wall while saying please step aside, she explains grumpily. "It's a bit annoying because then he's also right in the middle, so we can't do either," she says and goes into the elevator.

Apparently, the elevator is where the Hubots are challenged. I sit down next to the elevator to see for myself. While I am sitting here, several people take the elevator up and down - and I know that one of the robots is on the floor above, waiting to be able to go down. For it to do that, the elevator must have been free of activity for 15 seconds. But right now, at 9:40 am, there is so much traffic that the robot will be on top for a while, I would guess. 1 person comes down, 4 go up, 0 come down, 1 go up. Another 1 goes up. 1 comes down. The elevator goes up again. Will the Hubot come down now? No. 2 co-workers come down. 1 goes up. 2 come down. 1 goes up. And now the Hubot finally comes down, after sitting upstairs for 11 rounds. Staff often take carts in the elevator - and those who don't, apparently don't take the elevator with the robot in it. It seems as if the waters are divided: those who avoid taking the elevator with the Hubots because they think it can break down - and those who think it's okay to take the elevator with the Hubots.

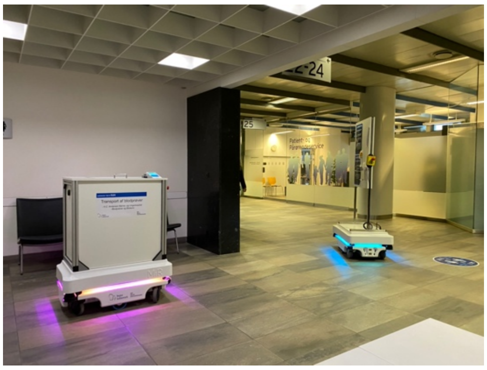
Suddenly, I'm met by the same critical voice as before, she asks how long I'm going to keep staring at the robots. "I can't tell Esben this, so you can't tell him I said it. But the Hubots are causing problems. They just stop. They stop. They've also stood in front of each other and said step aside, to each other - so, that happens often. This was one in the elevator - and one outside. So, Hubot is not reliable. " "It's good that you're discovering these things so you can tell Esben, so he can fix it and solve the problems." "We can't tell Esben. Because he thinks it's fantastic.

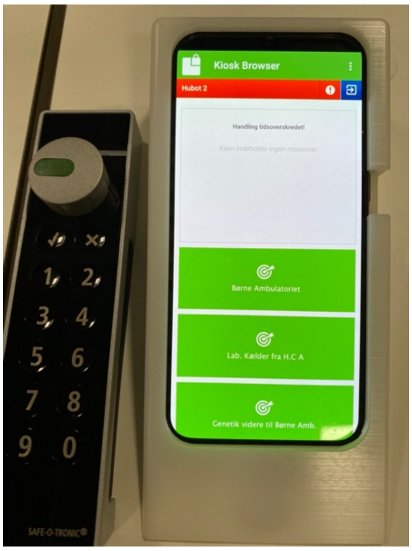
"You shouldn't say anything bad about it. I almost wish it would do something, so you could see how bad it is. And I know Esben can see things on his screen, but you must be able to see that it's not meant for someone to sit and stare at a screen all day. Right? If we're going to have 30 of them out at the new OUH, what? Should we also have 30 electricians then? God help us. I tell her very little about the robots' maps and zones and she says "Yeah, I don't know anything about that. But I just think it's incredibly annoying when I have to go in the elevator and think

YES, there's no robot; and then the robot is still here, inside the door." "If you are only going in alone, it's okay - but if you have to bring a cart in, forget it. It could just drive into the corner, then there would be plenty of room?! And I don't understand why it can't turn around while the elevator is running, I mean... it sometimes takes so long to figure out how to turn that the door closes.” She tells me that the only problem is with the big Hubot, as the other one doesn't run as often (?). And it shouldn't have so many childhood illnesses, it has been here for a long time, right!” ”Does it interfere with your work?” ”Only when it blocks the elevator. We are so dependent on it. And it is the only one that runs in the basement. And we have many things standing in the basement. But I don't want to stand and press a lot on it, so I just go up to the expedition and say now Hubot is not running. I mean. Bum.” ”But can't you press something on it to solve the problem?” ”You know what, you can probably do that. But you can see that if we all start standing and pressing on them... I don't think that's what we should do, really. No.”

I reach a point where I need something sweet to keep me going, so I rush to the hospital kiosk and buy candy. To my great appreciation, it turns out that a bag of M&M's fits perfectly in the pocket of a lab coat. I find comfort and luck herein, then no one can see that I run on chocolate - and then I move further on.

In the lobby, I spot Little Hubot, who just stands there. It has stopped and the time horizon for completing the task has been exceeded, it says on its screen. Interesting, I think. I sit down to see what it might lead to. Little Hubot stays here for a while and after 25 minutes of waiting for some action, I go ahead on Hubot2's route to see what triggered it to stop here. It turns out that Hubot2 is waiting out there for Hubot1 to move away from the area around the elevator, on the genetic ambulatory, a little further ahead. Here at the elevator, where I am now, Esben is fidgeting with Hubot1 while a BA, BA2, stands next to him. "It looks wild," I say. "I have a service message, Little Hubot is standing still out on the hallway, out there." Esben replies, "Yes, that's because it's waiting for this one to leave the zone."



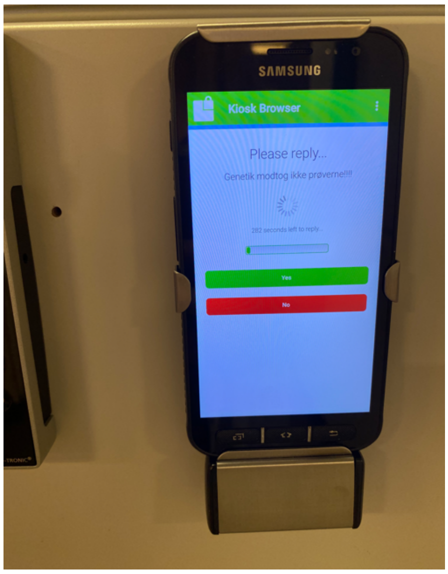


"So that's why it's been standing there for so long!", I say. BA2 says that the Big Hubot was blocking the elevator and Esben adds "It's set up so that only one can be in front of the elevator at a time, so the other is waiting. But this one has run into the elevator frame for some reason, I really don't understand it... Maybe someone pushed it, I'll leave that unsaid.." "Isn't it too heavy to push?" "No, you can definitely do it. Both in front and to the side." Esben resets the Hubot's missions and types them in again while saying "Now there are already 3 people who have called me about the Hubot standing still here." "But that means they can't actually be here at the same time, Esben, now that Hubot2 is standing there waiting for Hubot1 to leave?" "No, it's coded so that they can't be here at the same time." I ask how an employee can have experienced the Hubots "dancing" with each other and he says "That's what happens sometimes when it's in the elevator. If the door opens, it can think it's on a different map than it is. So it thinks it's in the basement, but it's here. And when the other comes... Then you have the trouble, because then it can't get in, for it."
Esben is tasked with putting the things that need to be with Hubot1 into the cabinet. But now the cabinet won't unlock. “Esben, what do we do here, with him? He won't unlock. What's wrong with him? We've opened him before, but he just must keep going. He won't talk to me. He doesn't want to cooperate! He just stands there and stares.” They're having major problems with the lock buttons and as they're firing questions at Esben, little Hubot comes tumbling in and stops next to us. Now Esben is also confused. “Esben, don't you just send Hubot on for us, huh?”, asks BA2 and her colleague. He nods and looks very confused, because little Hubot shouldn't be able to come in here when the big one is still here. “I didn't think this could happen?”, I ask. “Naah, nooo… It shouldn't have been able to…”, he says with a stiff smile. “Eeeeehm…..” Esben also tells me that he never has problems with the lock buttons. I can tell him that one of the BA's has told me that the problem is no longer that big for them, after he has replaced the lock on one of the robots with a new one. “Oh. Well, I haven't. I said I would do it, but I haven't gotten around to it yet.. It must be a placebo effect! I've bought a new one, because it's true, there's something wrong with the one on hubot2 now.”, he says, as he presses on the smartphone on little Hubot, to find out why it suddenly stands here. “Oh, there's just something I need to go research, because this shouldn't be able to happen.

I follow big Hubot down to the laboratory. When I saw it by the elevator upstairs, I could see that there was Christmas decor, in the form of a Santa with bells, on top of Hubot's cabinet - and I have a clear suspicion of who is behind it, after talking with BA4 earlier in the morning. Esben also told me that he is very critical of Santa's and Christmas decor on top of the robots, and often removes them, to remind the employees that the robot is a serious agent that runs with important blood samples, in a hospital. I find him in the laboratory and ask if it could be him who decorated Hubot: "Is it you who put Christmas decor on big Hubot now?" "Øøøøh, yes, or - I was involved in it", he says and laughs. "We were bored when we decorated in the Sample Receiving and then we thought, that should be on there! And it jingles! It just means we love him, right!" "What about Little Hubot, should he be decorated?" "I don't know if we dare, because there have been all these problems with the hygiene nurses, eeeh… I also don't know how Little Hubot feels about Christmas decor." "But there haven't been problems with the hygiene nurses on the big Hubot?" "We don't talk about it, eeehhhh", he says and laughs. He thinks it's hilarious and cosy that Hubot has been equipped with a Santa - and I think it's funny that he apparently has a very close relationship with Hubot1, but not with Hubot2, since only the big one should be decorated and is referred to so warmly, as is the case.

While we were talking, little Hubot came driving. I walked over to a BA who was about to start emptying the robot of samples - she looks like one who is having trouble typing the code and I ask, "Hey, are you also one of the many who have problems with the buttons?" "YES!" she says relieved, maybe because she feels seen and heard. She continues "But these buttons here, they're just so hard to press. The big Hubot isn't as difficult, but this little one here, you have to be very precise." She tries again and again. In the end, she succeeds and empties little Hubot and sends it back to the Children's hospital.

I follow big Hubot to see what reactions (if any) the jingling and rattling Santa Claus is causing. The staff in the laboratory smiles and laughs at it, one says "Yes, now we can hear when he comes, that Hubot", another says "There usually comes more on throughout December". At the elevator, a male employee removes a cart that has been standing in a place where it would be in the way of the Hubots. "I just got told it shouldn't stand there," he says. "Apparently there's something with this loading dock, it's too low for the robot to see it and then it can tip it over. It's something new, I just found out now." I smile inside at the thought that my observations seem to have made a difference in the corners where the robots are in the hospital. That what just happened must surely have a connection with the things I told Esben earlier - about the hand sanitizer dispensers and the scooter. Earlier in the day, I had taken a picture of Hubot2 that was just about to hit the cart."



"Hubot runs up to Genetics with samples. But no one receives the samples upstairs, so Hubot starts a countdown on the smartphone screen. When the time runs out, it runs with the elevator down again. It runs back to the laboratory but does not play the usual arrival sound. I walk over and sneak a peek at Hubot's smartphone and on it, it says "Genetics did not receive the samples!!!" On Hubot's smartphone another countdown runs "282 seconds left to retry", it says - and then the staff must interact with the screen. I walk away from Hubot again and stand a bit aside. There is a lot of talk in the laboratory, no one notices that Hubot is standing there, no one does anything - everyone is busy with their own things. Will anyone react? I stand and wait for a long time. No one goes to the robot. It just stands there. Suddenly, a foghorn from another world sounds and people react: "okay!", "ej, quiet!", "are we at war?!", "whaaaaat was that?!", "shhhhhh!!!!" and "woooow". "That was a FERRY sound," says one, while another says "I've NEVER heard him say that before!" "SHUT. THE. FUCK. UP. " A BA goes to Hubot, and I tell her that there was no one to receive the samples at the Genetic Outpatient Clinic, because she seems very confused about the situation. "Well, there are also a lot of new people started up at the outpatient clinic. I'll just write a note," she says. She looks for some paper. She comes back and still seems very confused. She eventually sends Hubot off again. But it won't drive, now there is a message about "awaiting space at the elevator." She doesn't know what that is now, she says - but I know that it must be because the space in front of the elevator is occupied by Little Hubot. And sure enough, shortly after, Little Hubot comes into the laboratory and Big Hubot can leave. I follow Big Hubot, as I am curious about how the further process here will unfold. The robot runs back up to the genetic outpatient clinic, stops and plays the sound that says, "Samples have arrived." It does it twice. Now we'll see if anyone comes and receives the samples. No one comes to Hubot. We wait again for a short time. Suddenly, a BA comes walking, but not towards the robot. I catch her to ask how long such a robot can stand like that. "Well, is there something in it now?" "Yes, it ran up here earlier and advised that no one received it, it ran down and now it has been sent back up again." "Okay, fine. I'll just empty it and activate it to continue from here. Locks it, says it can continue, it's locked, then it drives. Voila!" In the hallway, Hubot and I are overtaken by two women who laugh and look at Hubot's Santa and say, "It's going to be quite taxing if it has to make noise like that, all December!""

Investigating human-robot cooperation in a hospital environment

Scrutinising visions and actual realisation of mobile robots in service work

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ABSTRACT

This study analysed work activity in a hospital basement where humans and robots interacted and cooperated on logistics tasks. The robots were deployed to automate parts of courier processes and improve the work environment for the hospital's kitchen staff. Human–robot cooperation was studied through ethnographic fieldwork relating to mobile service robots and hospital kitchen staff. The results highlighted problems arising through the assumption that the 'plug and play' service robots could effectively automate work tasks. The analysis revealed the complexity of human–robot interaction in dynamic work settings such as hospitals and identified contradictions between the envisioning and realisation of robots at work, as well as the visible and invisible procedures underpinning human–robot cooperation. Consequently, we emphasise the importance of considering robots as agents of change and draw attention to the new work practices that arise when robots assume the roles of workers in dynamic work settings.

CCS CONCEPTS

• **Human-centred computing**; • **Human computer interaction (HCI)**; • **Empirical studies in HCI**;

KEYWORDS

Human–robot cooperation, hospital, service staff, invisible work

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1 INTRODUCTION

In many countries around the world, healthcare systems are changing and developing rapidly. Illnesses and diseases can be diagnosed and treated more effectively than ever before by, for example, using advanced technology and progressive medicine. Such developments are both necessary and appreciated because the ageing population in many countries places pressure on healthcare systems, and the outlook for pathological conditions involves an increasing number of patients with needs for hospital treatment, along with higher life expectancy and complex disease courses.[1] To meet the growing demand for superior healthcare services, hospitals must use their resources as effectively as possible by working smarter, optimizing their workflows, and minimizing non-productive activities. One promising way to achieve this is to assign repetitive, time-consuming, and heavy tasks to robots, developed to perform such work quickly and effectively without the inconvenience of breaks, days off, or breakdowns. In general, the purpose of deploying robots in hospitals is to automate processes and procedures that were previously performed by humans, enabling humans to spend more time performing complex logistics tasks that robots are incapable of carrying out.

In hospitals, logistics processes involve many routine procedures that need to be maintained. These can be characterised as invisible work, since they are the underlying processes that generally go unnoticed. As pointed out by Star and Straus [2], the relationship between visible and invisible work is problematic. Lack of attention to tacit and contextual knowledge, acquired expertise, and teamwork can cause dramatic shifts in apparently stable work processes [2, 3]; hence, research on human–robot collaboration in these types of invisible work settings is important for understanding and advancing work practices when robots take on the roles of workers in dynamic work settings.

There is a lack of work committed to understand the effects of deploying robots in work settings, but in recent years, human-centred perspectives on technology in the everyday life have received increasingly attention.

Researchers have argued for a new paradigm within Human-Robot Interaction (HRI), Critical Robotics (CR): a research field critically reflecting and researching how this technology is part of real-life settings. Researchers in CR [4–6] advocate for putting humans in the centre of HRI research and research robot technology holistically while focusing on values driven by technology [7, 8].

This paper contributes to the holistic focus in HRI research by investigating the use of mobile service robots in a real-life work setting and paying specific attention to understanding human–robot cooperation on service tasks in a hospital basement. Our research aimed to explore implications of workers cooperating with mobile service robots, in order to gain understanding of robots in practice, in a rather under-investigated area, which can lead to shaping future cooperation between humans and technology in real-life settings.

2 BACKGROUND

2.1 Logistic robots in hospitals

Within healthcare settings, robots have been deployed to perform personal and professional tasks. Mettler and Raptis [10] distinguished between robots designed for use within clinical or care facilities and robots designed for nonclinical contexts, such as in patients' homes. The professional use of robots for healthcare further distinguishes between systems that are already deployed—such as robots for operations, surgical training, exoskeletons, prostheses and bionic limbs; therapy robots; assistive robots; telepresence robots, cleaning and disinfection robots; and logistic robots—and robots as manifestations of wishful thinking, such as robotic nurses and robots for keeping patients company. This study focused on logistic robots, which are often categorised as service robots since their purpose is primarily to assist humans with service tasks. [11] According to the ISO 8373 standard [12], a service robot is 'a robot that performs useful tasks for humans' and usually does so in cooperation with humans in dynamic environments (for example, hospital hallways) without surveillance or monitoring. Such robots have certain degrees of autonomy, which give them the ability to participate in daily routines and accomplish tasks (e.g. logistic robots handling transportation tasks) [13, 14]. Logistic robots are often designed to attach to or carry carts, allowing them to transport food, laundry, and other items from one defined point to another. As presented in this paper, these robots can, for example, transport kitchen service items from a hospital kitchen to a ward and are intended to improve workflows and hospital effectiveness. Research on the potential of logistic robots in hospitals found that automation can improve logistics efficiency in hospitals, reduce costs, and facilitate organizational improvements. [15, 16]

2.2 Cooperating with logistic robots in hospitals

Research advocating human-oriented approaches towards robots in real-life settings and aiming to understand humans and robots interacting and cooperating, has indicated that organizational factors impact the working relationship between the two parties. Well-being, including tolerance to interruptions and stress, has a great impact on how robots are experienced by the hospital staff who cooperate with such technology. Mutlu and Forlizzi's [17] ethnographic studies researched mobile robots in hospitals and found that different hospital wards perceived the same robot in different ways, due to varying levels of tolerance to interruptions: staff on a hospital's medical ward saw the robot as interrupting their work, while the staff on the post-partum ward had a less disruptive experience with the robot. Thus, the composition of a working environment influenced how hospital staff cooperated with robots, since the post-partum unit did not have as much traffic as the medical ward and did not deal with such urgent crises.

Human-centred studies of robots in hospitals have reported how human perceptions of robots in a workplace can change over time as human workers become more familiar with them. Ljungblad and colleagues [18] researched hospital staffs' perceptions of a robot transporting blood samples in an orthopaedic unit and found that perspectives on the robot adjusted over time as staff developed closer working relationships with the technology. These authors present a model on how the robot is often first perceived as something alien and machinelike and eventually as a coworker [18].

Mettler and colleagues [19] demonstrated that hospital staff cooperating with service robots had concerns about the complexity of the robots and the difficulties it might cause if this technology was integrated into hospital environments, claiming that some hospital staff were unable to think of robots as anything other than gadgets. Additionally, Cresswell and colleagues argued that humans' initially negative attitudes towards robots at the start of an exposure period are embedded in three major elements: lack of trust in the robots, fear of the robots threatening professional roles, and fear of the unknown [20].

Our research investigates how the mobile robots were respectively anticipated and used in practice in a hospital setting, aiming at understanding how robots and humans cooperate in dynamic work environments.

2.3 Researching human–robot cooperation

Although research on human–robot collaboration in dynamic shared work settings is scarce, research on collaboration on work mediated by technology is rich, especially regarding computer-supported cooperative work (CSCW). As explained by Schmidt and Bannon [21], this research field is comprehensive, interdisciplinary, and heterogeneous, but characterised by a focus on problems relating to the design and use of technologies at work. Research attention has especially been paid to understanding coordinated practices at work [22, 23], drawing attention to assumed models of use [24] and a general need for 'systematic studies of actual cooperative work practices in real-world settings' [21] to unpack the practices that underpin the automation of work and highlight the situated character of work [25].

The phenomena and concepts of work have been widely debated in the CSCW research field, especially regarding whether 'work' only refers to paid work and highlighting that activities carried out in the private sphere are also work [26] (e.g. work relating to living with chronic illness) [27]. However, as emphasised by Schmith [28], the key focus of this line of research is on cooperative work, which is highly complex, often characterised by interdependencies, and 'requires and exhibits highly developed and often sophisticated coordinative practices of a nature that one rarely, if ever, finds outside of ordinary work settings' [28 p.392].

Our research was grounded in this perspective on cooperative work, paying specific attention to investigating not only formally defined work activities, but also conducting empirical research.

Figure 1: A MiR Hook 100 robot with a hospital kitchen service cart attached

The aim was to understand the cooperation between humans and robots on service tasks and discover the undefined, invisible work processes that often go unnoticed when technology is deployed to optimise workflows and facilitate shared tasks with humans.

The following Methods section presents the methods through which these phenomena were researched.

3 METHODS

This research investigated the complexity of human–robot work activity in a dynamic, shared environment in a hospital basement, where humans and robots interacted and cooperated on logistics tasks. The study was conducted in a medium-sized Danish hospital with approximately 3,000 employees across its operational region. The region covers a population of around 228,000 people, and at the unit level in this study, the hospital mainly carried out planned same-day surgeries, the treatment and monitoring of chronically ill citizens, and the treatment of injured locals and outpatients. The hospital deployed service robots to operate in the basement, where hallways are narrow and traffic (constituting a mix of patients, clinicians, laboratory technicians, kitchen staff, porters, technical staff, and workmen) is heavy.

3.1 Robots

In 2016, the hospital in this study deployed two mobile MiR Hook 100 TM service robots, which are autonomous, mobile service robots with an attached hook, developed to pick up and unload carts (see Figure 1).

This type of mobile service robot is widely used in industry, operating largely without human interaction, but these robots gradually gained acceptance in this hospital as a means of optimising logistics and were, consequently, interacting with humans in a dynamic environment in the hospital basement. These robots identified service carts that needed to be picked up from various hospital locations using QR codes and were equipped with sensor input, enabling the robots to evaluate the current setting and avoid driving into (human or inanimate) obstacles.

Furthermore, both robots had a large, red 'STOP button' that, when pushed, stopped the robots immediately in case of an emergency and a joystick for manual operation. The robots communicated with their surroundings using sound and light signals, which indicated the planned direction and the status of the current tasks they were performing.

3.2 Informants

Twenty-six people participated as informants in our study, all of whom were employed at the hospital, where most of them were kitchen staff (n = 16), two were kitchen service managers, one was a healthcare professional, and seven were porters, as shown in Table 1

The participants were recruited through snowball sampling [29]: The first author established contact with the hospital's kitchen manager, identified by members of the first author's professional network. The manager permitted access to the field, invited the hospital staff whose daily routines were based in the cellar to voluntarily participate in the research, and provided them with information about the study. The informants were then gradually recruited by the first author during the field study based on their interaction with the robots: the kitchen staff were included in the study because of their extensive cooperation with the robots, the healthcare professional was included because she impulsively interfered with one of the robots, and the porters were included because they had several interactions with the robots throughout the day. The informants also contributed to the observed traffic, along with the other humans in the basement, such as patients, clinicians, laboratory technicians, technical staff, and workmen. Throughout this paper, informants will be referred to by numbers such as *Informant #1* to ensure anonymity.

3.3 Data collection

We collected data through an ethnographic field study during May 2020. The methods used to gather empirical insights consisted of interviews based on an interview guide, observations of robots in action, and guided tours during which informants explained their actions when performing tasks and cooperating/not cooperating with robots [30, 31]. The aim of using a mixed-methods approach was to deepen understanding of robots in a hospital setting, observe the setting at first hand [32], investigate cooperation on tasks and procedures, explore the informants' visions of robot deployment, examine the actual everyday practices of robots at work, and uncover the hospital staffs' perceptions of working with robots [33, 34]. Furthermore, the robots were shadowed by the first author during their performance of daily routine tasks [35]. The data was brought back from the field in the form of descriptive field notes, photographs and videos, and audio recordings of interviews.

3.4 Data analysis

The audio recordings of the interviews and guided tours (598 minutes in total = 9.97 hours) were transcribed, the photographs and videos were examined, and the empirical data was analysed according to Braun and Clarke's techniques for thematic analysis [36].

Table 1: Overview of informants in the field study in the hospital

Overview of informants n =			
Total number of participants			26
Gender		Male	8
		Female	18
Profession		Kitchen staff	16
		Porter staff	6
		Kitchen management	2
		Healthcare professional	1
Age group		20 - 29 years	7
		30 - 39 years	6
		40 - 49 years	7
		50 - 65 years	6
Robot cooperation	Supposed to cooperate with robot		16
	Does not cooperate with robot		8

The transcripts and field notes were printed and colour-coded manually with markers. The coding resulted in 64 codes based on careful attention to identifying human–robot cooperation. The codes were organised into 12 themes: reliance, attitudes, errors, conflicts, pace of work, types of tasks, divisions of labour, perceptions, environment, irritation/frustration, 'war stories', workarounds, breakdowns, handovers, safety, and behaviour. The themes were reviewed to determine how the human–robot cooperation affected the work processes and procedures and how work was structured, planned, and carried out. In addition to the thematic analysis, Beyer and Holtzblatts' [37] work models were used to analyse the empirical data; identify the key aspects of work (such as strategies, roles, coordination, and structures); break the work processes down into steps to distinguish the robots' tasks from the humans' tasks; and identify the rich patterns of the agents' work. Flowcharts were designed, inspired by Jurgensen [38], to map and visualise how the work was divided, coordinated, and organised between humans and robots. The thematic analysis and flowcharts resulted in the identification of three key themes, which are presented in the following sections.

4 FINDINGS

4.1 Robots in a hospital setting

The key finding from the field study of robots in a hospital setting was that several obstacles presented challenges for integrating robots in a working environment. The hospital's kitchen manager explained that the aim of deploying robots was to ease the work of the kitchen staff following the implementation of a new food concept for patients. The hospital intended to provide patients with a higher quality food experience during their stays in the hospital and therefore deployed the robots to support staff in their daily work routines and relieve them of physical tasks, such as transporting carts with cutlery, glass, and dishes around the hospital. In an interview with the deputy kitchen manager, she explained this vision and shared how it was realised by the robots.

During the field study, the first author observed how the robot picked up a cart by using its hook, attaching itself to the cart, and pulled the cart around the basement to place it in another predefined spot, where the hospital kitchen staff could collect it, push it inside an elevator, and take it a hospital ward for use (see Figure 2). The robots' joysticks, located on their front casings, were a requirement of the hospital's management, enabling different hospital staff groups to manually drive the robots around in urgent cases, such as robots driving in front of staff handling emergencies. Additionally, it was possible to set the robots up in manual mode and control them through a specific tablet. When the robots were not running missions, they were parked for recharging in a room called the 'Robot Garage'.

The robots mainly performed tasks coded in a fleet management system (through which they functioned) and performed tasks/missions that the kitchen staff could define through a tablet located in the Robot Garage. Some kitchen staff informants (n = 8) showed how they gained an overview of the robots' locations through a map on the tablet, as long as the robots were operating within a certain distance from the tablet. If the robots went beyond this distance, the staff lost the connection and ability to track them, which necessitated them physically searching the hospital hallways for the robots. A kitchen staff informant reported that she and her colleagues were unable to locate the robots on the map if they drove out of range, if they had been turned off, or if they ran out of power (Informant #7).

In the interview with the hospital's kitchen manager, she explained that she and the rest of the management team decided to give the robots names to ease the acceptance of the technology by different groups of hospital staff. They named the robots Prop and Berta, based on a popular Danish children's book and movie about a man (Prop) and his best friend (a cow called Berta). Prop and Berta only operated in the basement, because they were unable to fit into the hospital elevators when the carts were attached. Consequently, the robots only pulled service carts and did not transport supplies to hospital wards. The kitchen manager also explained in an interview that the decision to focus the robots' tasks on kitchen services was a result of the robots not being reliable enough for

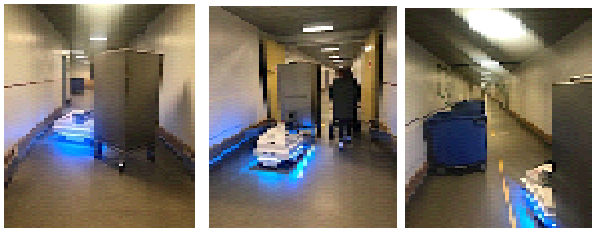

Figure 2: Mobile service robots driving in the narrow hallways of the hospital basement. The picture on the left illustrates how much space a robot with a cart attached took up in the hallway; the picture in the centre shows how a robot with a cart attached passed a patient in a wheelchair and her relative; and the picture on the right demonstrates how crowded the hallways in the basement could become, limiting available space.

the hospital management to charge them with critical tasks such as transporting blood.

In the hospital basement, the hallways were narrow and the robots were therefore programmed not to drive alongside each other. As shown in Figure 2, the hallways were not suitable for several types of traffic at the same time; hence, the robots could only navigate around humans with a certain amount of surrounding space available (for safety reasons), and they took wide turns for mechanical reasons. A consequence of the narrow hallways combined with the wide robot movements was that the robots took up a great deal of space in the hallways when working.

4.2 Visions for and actual realisation of the robots' work

Through the study, it became clear that several issues affected the cooperation between hospital staff and robots, which staff members had to deal with daily. In the interviews and observations, it was evident that the vision of simple automation being able to handle work tasks and procedures was unrealistic in practice. During an interview with the kitchen leader, she outlined that the vision of deploying mobile service robots in the hospital was to save time and optimise the work processes of the hospital kitchen staff: 'In my opinion, the robots are definitely giving great aid to the kitchen staff, who would have been unable to accomplish the considerable number of tasks they have without the robots' automated performance' (Informant #18).

According to the kitchen leader, the robots were deployed following the new meal concept in the hospital, which had to be implemented without additional resources, except the robots, being given to the kitchen. She explained that, consequently, tasks that could not be completed by the current staff had to be automated and performed by the robots, constituting robot labour as an inevitable factor in the daily work processes. The deputy kitchen manager elaborated on how the robots were supposed to relieve the kitchen staff of routine work and improve their work environment, saying: 'Our kitchen staff are no longer supposed to push and pull the heavy service carts across long distances in the hallways of the hospital. Now they only have to make minimal physical effort in the task of transporting stuff' (Informant #17). However, only a single courier task was performed by robots: transporting service carts from one identified spot to another. This observation is illustrated in Figure 3. To enable a robot to pick up a cart and transport it, the kitchen staff had to collect a cart from the kitchen (located on the ground floor), take it down to the basement in an elevator, and place it in a certain spot, such as the Robot Garage or the hallway. This procedure was necessary because the robots' size made them incapable of fitting into the elevators when carts were attached. From that spot, the robot could collect a cart and transport it to another destination (e.g. Temporary Destination A), where a member of the kitchen staff would take the cart and transport it to Final Destination B, which was usually located on the higher floors of the hospital (Figure 3).

This finding highlighted that the hospital's kitchen staff actually acquired a new type of task after the robots were deployed: placing the service carts in certain locations for collection by the robots.

Additionally, an unexpected finding was that 5 of the 16 kitchen staff members were following the robots around when they were transporting carts. These informants were spending time taking care of the robots and aiding them in fulfilling tasks. When interviewed, the staff members explained that they followed the robots in case something went wrong during the robot's mission, and all five informants pointed out that they did so because they had previously noticed errors when the robots were performing tasks. Hence, the study found that 'minding' the robots was also a new type of task for the kitchen staff following the deployment of the robots. These findings raised important questions about the implications of deploying robots to optimise work processes, since the empirical data showed that, although the hospital's kitchen staff were relieved of heavy work tasks, they spent considerable amounts of time assisting the robots.

Another important finding that unfolded during the interviews was that 50% of the kitchen staff informants preferred to work without interacting with the robots. Eight of the sixteen informants who were supposed to share the daily courier tasks with the robots explained that they preferred to push/pull the service carts around the hallways themselves because they could not rely on the robots to fulfil these tasks. Consequently, they felt it was more effective to perform tasks themselves, and one of them said: 'Something always goes wrong. Errors occur and the robots do not do as they are told, so we can't rely on them to accomplish their missions. If I want something done, I will do it myself' (Informant #5). For this reason, we referred to these informants as *non-users.* Six of the eight non-users explained that, apart from their unreliability, they did not want to use the robots during their daily work routines because the robots slowed down their work. These six informants stressed that this happened because the robots ran slowly, not least when they took time to assess their surroundings for (as the informants said) uncertain reasons. This observation was important since it highlighted conflicts in balancing the work tempo in the cooperation between humans and robots. Furthermore, the non-users stated that they could work faster themselves and did not consider the heavy pulling/pushing to be a problem; rather, the robots could be a source of frustration due to errors that influenced the work hours. One of them said:

Honestly, the robots are more a source of irritation than a helping hand! Don't get me wrong; it is fine when they are working without

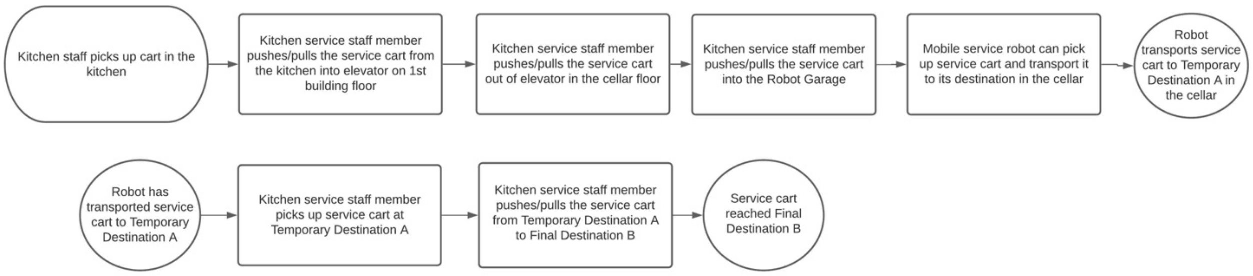

Figure 3: A visualization of the observed steps for transporting a service cart from one spot to another

problems, but errors occur so often . . . It really can be a waste of time to use Prop and Berta, you know? (Informant #2).

This was a key insight into how the kitchen management's visions for the robots as a mean to optimize the work procedures were not shared by the kitchen staff, who perceived the robots as a complicated and time-consuming source of extra work.

The study also found that the robots only helped kitchen staff to transport service carts carrying glass, cutlery, and dishes, since the staff still pushed/pulled carts containing food around the hospital. In an interview with the hospital's kitchen leader, she said that transporting food was not a task the robots could carry out, since the hospital had found robotic operations to be unstable. She elaborated that she and her colleagues found the robots unreliable for completing critical tasks.

Taken together, these findings supported our developing understanding of how humans and robots work together by illustrating why the visions of robots working in the hospital were difficult to achieve and why the realisation of cooperation between the kitchen staff and the robots was complex, leading to changes in the work rather than minimising work: the hospital kitchen staff acted as caretakers for the robots, despite the robots being deployed to carry out tasks and cooperate with the staff.

4.3 Visible and invisible procedures in human–robot cooperation

Through interviews and observations, it became clear that the procedures aiming to facilitate cooperation between kitchen staff and robots were complicated because the accomplishment of tasks comprised a series of invisible process s and interactions between the robots and the dynamic work environment. To carry out the daily work routines of the hospital kitchen, tasks were divided, coordinated, and distributed between the kitchen staff and the mobile service robots by the kitchen management. In an interview with the kitchen's deputy manager, she explained how the formal division of labour was assigned and clarified why it was a simple task for a robot to move a service cart from point A to point B: the robot would simply drive up to the cart, attach itself to it, and move it from point A to point B, as shown in Figure 4

In this workflow, the robot was sent on mission and drove off to accomplish it by moving down the hallway, approaching and attaching a cart, and then simply bringing the cart back to the Robot Garage. These processes were apparently simple, but guided tours with kitchen staff and robots showed that several steps and procedures for performing these tasks were unspecified, invisible, and informal. It became clear that the robotic workflows were far more complicated than envisaged by the kitchen's management and kitchen staff informants. Figure 5 visualises the steps observed during a single tour following a robot, which was performing the task of transporting a service cart from one point to another in the basement. Including a total of 28 different steps, in sharp contrast to the verbally reported 7-step workflows, this visualization presents an overview of several procedures and interactions that were invisible in the formal workflow shown in Figure 4, drawing attention to why robotic task performance in a dynamic environment must be considered as complex, comprehensive, and context dependent, rather than a simple, isolated automation of tasks.

As visualised in Figure 5, when a robot was sent on a mission by a member of the kitchen staff, the robot drove away from the Robot Garage and into the hallway extremely slowly to avoid crashing into the narrow door frame. The robot would then drive into the hallway and enter an environment that held mixed traffic; therefore, the robot would loudly announce its presence using alerting sounds and flashing lights (steps 1–5). Steps 6–11 visualise how a porter approached a robot too closely, which made the robot stop and the porter furious, since the robot was slowing down his work. In step 13, a healthcare professional pulled out in front of the robot with the consequences shown in steps 14–19. In step 14, the robot stopped as soon as its sensors registered movement and then started to play loud, alerting sounds ('Please step back! Please step back! Please step back!'), with lights flashing, to warn people in the surrounding area. The healthcare professional started to express her frustration by swearing at the robot, and because the robot was immobile, still warning and recalibrating, a member of the kitchen staff approached the robot with a cart full of warm meals for patients that she was on her way to deliver (step 17). Unfortunately, she was unable to pass the robot, which had stopped in the middle of the narrow hallway, blocking traffic. Consequently, the kitchen staff member and the healthcare professional had to wait for the robot to recalibrate and drive on before they could continue with their tasks. However, they failed to recognise that the robot would not have stopped if the healthcare professional had not moved in front of it. After five minutes, the robot was ready to proceed (step 20), drove on, and then attached the service cart to its hook, making a wide turn that again blocked the narrow hallway, before driving on towards the

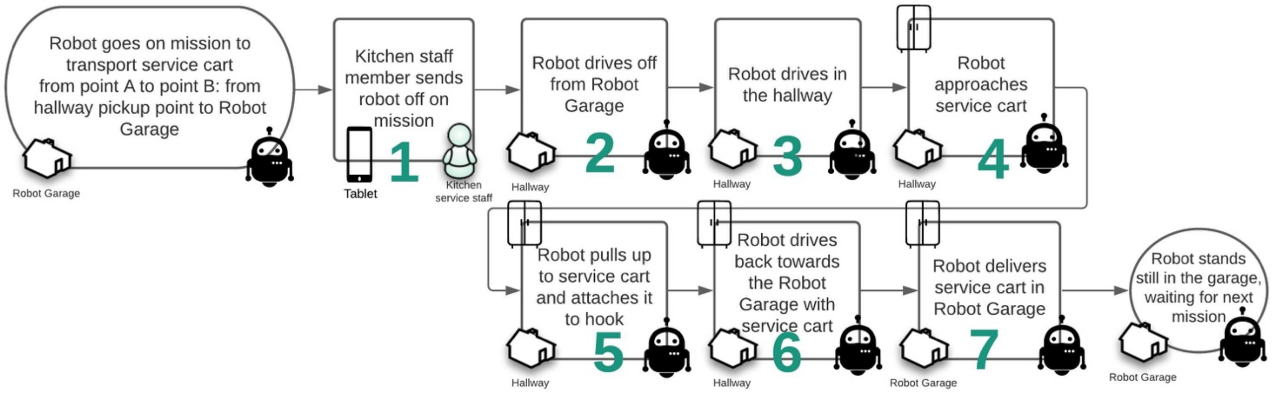

Figure 4: A visualization of the steps for a mobile service robot to perform a task, as expected and described by the kitchen's deputy manager

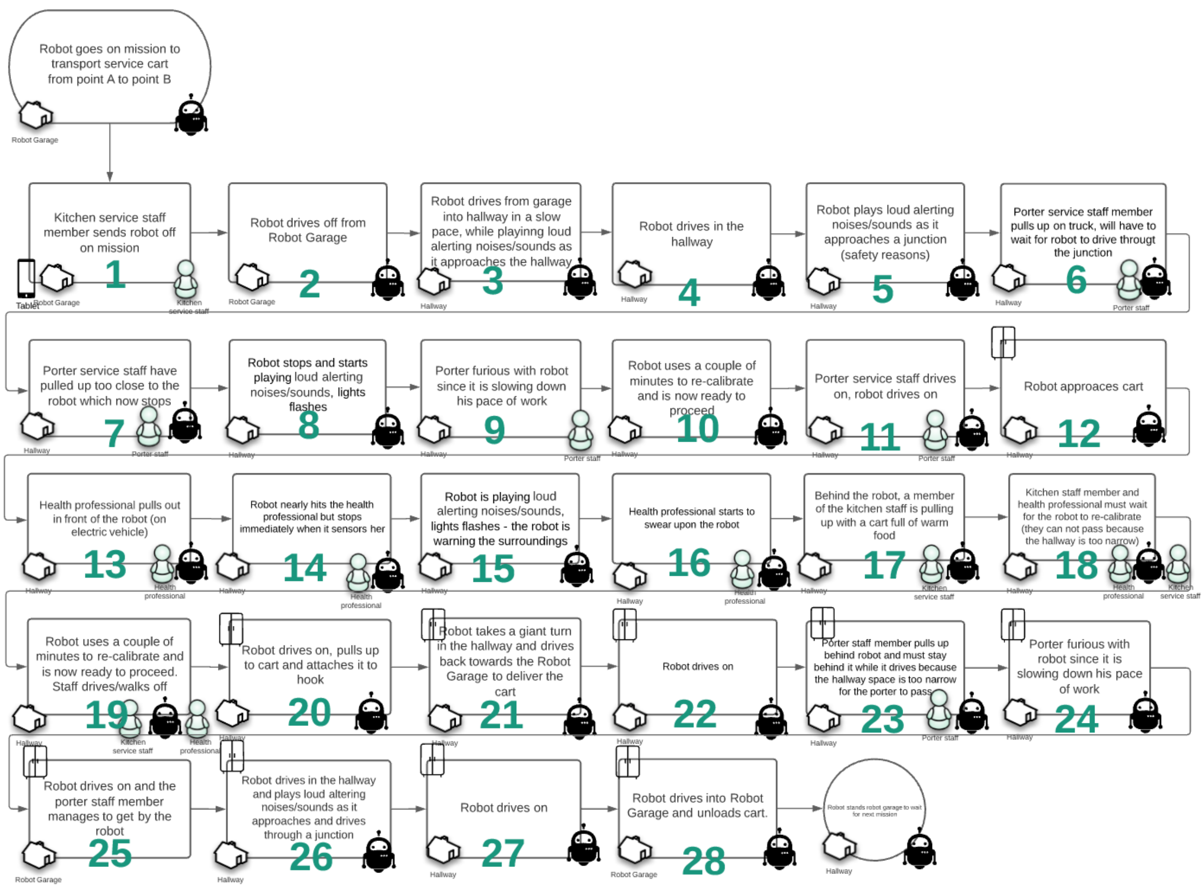

Figure 5: A visualization of the steps observed during a tour with one of the mobile service robots performing a task

Robot Garage to unload the service cart. In steps 23–25, another porter pulled up, in a truck, behind the robot and had to drive behind it, which made him angry because the robot was forcing him to slow down. In steps 26-28, the robot drove on and arrived at the Robot Garage, where it unloaded the service cart. When it had done that, the kitchen staff members were able to take the service cart to its final destination.

These invisible procedures developed because unexpected interactions between humans and robots turned out to greatly affect the everyday cooperation between kitchen staff and robots, but the staff were not aware of the complexity of the processes. Through interviews, the kitchen staff informants were asked to elaborate on how the robots completed tasks, and only 2 of the 16 members of the kitchen staff were aware of how many processes the robots had to execute during their missions. This finding implies that the cooperation between humans and robots is complex, since robots are deployed, and expected, to perform seemingly simple tasks, but the cooperation between staff and robots depends on a comprehensive and invisible set of interactions, adding to the complexity of deploying robots for new applications, such as in hospitals.

5 DISCUSSION

This field study revealed a series of empirical situations that highlighted the complexity of integrating robots into dynamic work environments and the problems that arise when robots' deployment leads to less-than-seamless automation of tasks and processes. Moreover, this research showed that simple automation's idealised ability to handle work tasks and procedures is unrealistic in practice because of three major elements. First, the studied robots changed the staff's work, rather than minimising their work. Second, the procedures which aimed to facilitate cooperation between kitchen staff and robots were invisible. Third, humans' cooperation with robots in the studied context was complex.

In the following section, we discuss these findings and recommend a holistic, ecologic view when introducing robots to dynamic work settings. This view must consider not only the staff who are expected to cooperate with robots but also other stakeholders, the environment, and similar factors.

5.1 Robots changing rather than minimizing work

Technological deployments—in this research case, robots—in work settings can change the nature of work, tasks, and effort. The robots we researched had been installed at a hospital to optimise work processes and relieve kitchen staff of heavy daily tasks. Our empirical study highlighted how these hospital kitchen staff members acted as caretakers for the robots and how these robots imposed additional tasks on the staff, rather than taking over tasks as intended to optimise work processes and save time. For example, the hospital kitchen staff took on new types of tasks after the robots' deployment, such as placing service carts in certain spots around the hospital for the robots to pick up. Generally, the kitchen staff spent a great amount of time helping the robots fulfil tasks. Consequently, the kitchen staff did not share the kitchen managers' vision of the robots optimising work procedures; rather, the staff perceived the robots as a complicated, time-consuming source of extra work.

Altogether, our findings showed how robots necessitate changes to everyday work routines, rather than minimising human workloads or replacing the human workforce.

5.2 Complicated cooperation due to invisible processes

Our research showed that cooperation between humans and robots is complicated because tasks required a series of invisible processes and interactions between the robots and elements of the dynamic work environment. The everyday challenges between kitchen staff and the mobile robots contrasted with managers' perspectives on these robots. Neither hospital managers nor kitchen managers seemed to completely understand the complexity of kitchen staff and the robots' tasks because many steps were invisible or informal. Managers may have expected the robots to be able to perform tasks automatically, but when this study identified tasks' steps and procedures, the actual work practices were exposed, and the informal practices that supported the work of both kitchen staff and robots became clear.

As our findings revealed, such invisible procedures result in unforeseen interactions between humans and robots. In our studied case, such unanticipated interactions greatly affected everyday cooperation between the kitchen staff and the robots as part of the hospital basement's dynamic work setting.

5.3 The complexity of deploying robots in a dynamic work setting

The cooperation between staff and service robots is complex. In this study's case, this cooperation was complex because the robots are expected, to some extent, to autonomously perform simple tasks, but their cooperation with staff depended on a comprehensive set of interactions of which managers were unaware. These interactions made the robots and staff interdependent, adding to the complexity of deploying robots to new applications, such as hospital work. Technological deployments in work settings affect the nature of work, as Mutlu and Forlizzi have shown [17]. They found that a work environment's composition influences cooperation between hospital staff and robots. In the same vein, our research revealed complications in robots' daily work tasks because of environmental factors, such as the presence and actions of other basement stakeholders (e.g. porters and kitchen staff). These complications led to a lack of trust in the robots among the kitchen staff, and some staff members consequently avoided working with the robots despite managers' expectations that staff would cooperate with the robots. This finding supported the work of Cresswell and colleagues, who asserted that negative human attitudes towards robots are embedded in a lack of trust in robots and a fear that robots will threaten jobs [20].

Our research contributes to the body of knowledge regarding coordinated work practices by elucidating automation-related practices and explaining the potential complexity of robots' deployment to shared dynamic work settings. Some of the challenges that occurred while the robots performed tasks were inherently technological (e.g. the robots' slowness and safety measures that made the robots frustrating for porters and other humans working in the hospital basement), but the core issue with the robots was their protracted process of integration into workflows in order to seamlessly cooperate with kitchen staff. This process remained ongoing years after the robots had been deployed to the hospital.

The kitchen staff did not seem to have adjusted positively to the robots' presence, unlike the hospital staff in Ljungblad and colleagues' research [18], despite the robots' having been installed at the hospital in 2016. In our research, the staff did not seek closer involvement with the robots because they doubted the robots' reliability in performing tasks. According to the hospital's kitchen manager, no guidelines established how cooperation between kitchen staff and robots could be achieved, nor were any descriptions available of appropriate workflows or cooperation processes. Therefore, complementary work tasks between staff and robots were difficult to delegate or coordinate. When work was distributed between humans and robots, tasks' complexity was not taken into account because a significant number of steps in human-robot cooperation were unknown to the kitchen manager who was delegating these tasks. This manager was unaware of the processes and steps required to perform tasks in the basement work environment.

5.4 Implications

Since this study exposed disparate beliefs about human-robot interaction and cooperation in a dynamic hospital work setting, we emphasise the need to think of robots as a new technology, rather than a familiar and tested technology which can be simply adjusted and applied. Implementing robots in real-world work environments requires more nuance than plugging in the technology and pressing a 'power' button. In the same vein, technology must be developed beyond 'one size fits all' solutions because work environments vary. The mobile robots deployed to the hospital in this study were of a type that had been widely fostered and used in industry, moving items from Destination A to Destination B in highly structured environments, where humans working within a certain range of the robots are instructed and educated in sharing workspace with such. Since this kind of use and training are not matters of course when robots are implemented into hospitals, the humans who share their much more complex, unstructured work environment with mobile robots experience several problems in cooperating with this technology, as in industry cases. If robots are to participate in real-world work environments and cooperate with humans, sociotechnical factors must be focal – not least because humans affect the environments to which robots must adapt. This focus is complex, though, since robots do not hold any degree of social (or artificial) intelligence and are, therefore, unable to adjust their behaviours, work, and routines to the humans around them.

Important prerequisites for the successful deployment of robots in work settings are broader perspectives on which work elements this new technology affects and increased awareness of robots' requirements to function effectively in dynamic environments while closely cooperating with humans. Based on this field study's findings, we suggest a holistic perspective on robots in the same vein as 'the ecological viewpoint' defined by Nardi and O'Day [39] as 'a system of people, practices, values, and technologies in a particular local environment' [39, p. 49]. We, therefore, propose a consideration of robots in relation to 'a dense network of relationships in local environments' (i.e. information ecologies) [33, p. 27], which implies including robots as part of an ecosystem and preventing their exclusion from their surroundings. This ecological viewpoint would promote an understanding of optimal cooperation and interactions between different groups of hospital service staff and robots. For example, the routines and workflows of the porters in this study did not seem to have been integrated into the robots' workflows and organisation after their deployment in the hospital; nor did managers consider or act upon the porters' attitudes towards the robots – despite the robots having significantly affected the porters' performance of their tasks. If the porters had been involved in the deployment processes and given an opportunity to influence the robots' inclusion in their shared work environment, we presume the porters would have experienced less frustration with the robots' presence in the basement.

In order to introduce an ecological, holistic viewpoint at the hospital we studied, discerning the invisible aspects of work would be beneficial. If even some of these steps in the robots' task performance had been clear, managers could have evaluated them, preferably in close collaboration with the stakeholders and professionals whose daily work took place in the basement. Managers could, thus, have understood what the robots could contribute to the context – the ecology – in which they were deployed. This involvement would have allowed stakeholders and professionals to discuss their routines, values, work performance, needs, and desires vis-à-vis the robots, enabling the robots' deployment to be closely tailored to their expected work context work.

5.5 Limitations and future work

In this study, we chose to limit our research to one single robot type, mobile MiR100 robots, in a single and specific work environment. We chose this focus and limitation because this type of robot had been deployed for the longest period at the hospital where we collected our study's data. Therefore, the findings we have presented might not apply to cooperation between other types of robots and humans in hospitals. However, our findings must be considered empirical material which provides insights into human cooperating with MiR100 mobile robots within a service domain.

This ethnographic field study of mobile service robots at work has improved the broader understanding of the complexity in considering human-robot cooperation within a dynamic work setting. Our findings highlight the importance of understanding broader work settings and human-robot interactions when implementing robots into work, calling for further investigation of the dynamics between humans and robots in complex workplace settings which are not designed for robots. This further research should include sociotechnical research into robots' impact in a context that holds several interdependencies, tasks, procedures, interests, and stakeholders. The acknowledged principles for stakeholder involvement are greatly important to human-robot interactions, and future research is needed on understanding and designing optimal types of human-robot interactions for multiple stakeholders in hospital service work. Our research has illustrated why managers' visions of deploying robots in a work setting were not fulfilled in reality.

When robots share work environments with humans, such visions seem to reflect high hopes among techno-enthusiasts and managers, but our research has shown a need to investigate the humans who actually interact and cooperate with robots in dynamic work environments in order to responsibly implement robots at work.

6 CONCLUSION

We investigated actual human-robot work activity in a hospital basement and identified how robots led to work changes, how invisible procedures caused complications, and why human-robot interaction and cooperation were complex. Our research has shown why the process of deploying robots to cooperate with humans must be acknowledged beyond the simple automation of work tasks. We have demonstrated that robots are agents of complex work changes and must be considered as such for any meaningful cooperation between robots and staff.

This research found that mobile service robots at the studied hospital were not considered reliable enough for critical tasks. Also, because they drove around the hospital basement with service carts, they took up a great deal of space, which especially frustrated porters and other staff members whose daily work routines had been disrupted.

This study has also identified complex cooperation between kitchen staff and robots. Our observations showed that everyday cooperation between kitchen staff and robots involved several problems – not least because a considerable amount of procedures involved invisible steps of work and different interactions between robots and the dynamic work environment. Our research gradually clarified that managers' expectations in deploying these robots to achieve simple, technical automation of work tasks and procedures was unrealistic in practice. The robots actually increased the kitchen staff's tasks, rather than optimising their workflows – not least because the kitchen staff tended to follow the robots around to ensure that they performed their tasks correctly, or the staff simply carried out the robots' tasks themselves. The hospital kitchen staff tended to become caretakers for the robots despite the robots' purpose of accomplishing tasks and cooperating with staff. Altogether, these findings provide an understanding of the key factors which underpin the complexity of robotic aid and assistance, revealing how robots necessitate changes in work routines, rather than replacing the human workforce.

Our findings in this study have revealed an apparent need to consider robots from holistic and ecological perspectives when designing them for, and deploying them in, work settings. Based on our findings, we posit that scrutinising robots in relation to their work surroundings and contributions would be beneficial.

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How Socio-Technical Factors Can Undermine Expectations of Human-Robot Cooperation in Hospitals

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Abstract. This research analysed human–robot cooperation and interaction in the basement of a Danish hospital, where kitchen staff and porters conducted their daily routines in an environment shared with mobile service robots. The robots were installed to ease the everyday routines of kitchen staff and carry out physically demanding tasks, such as transporting heavy cargo between destinations in the hospital basement. The cooperation and interaction were studied through ethnographic inspired fieldwork and the results highlighted how robots affect the real-life environments into which they are gradually moving. The analysis revealed how the great human expectations of robots clashed with reality and identified three key elements that influence human–robot cooperation in hospitals: 1) environmental factors, 2) behavioural factors and 3) factors related to human reliance on robots. We emphasise the importance of considering socio-technical factors when deploying robots to cooperate with humans in hospital environments.

Keywords. Socio-technical factors, expectations of mobile robots in practice, hospital, human-robot cooperation

1. Introduction

Robots have gradually moved out of controlled settings, such as laboratories and industry, into everyday real-life environments, including homes, workplaces, cultural institutions and public arenas—not least hospitals, which is the setting with which this paper is concerned. As robots increasingly enter new application areas—'the wild'—with diverse actors and unexpected responses, research on the relationship between humans and robots in real-life settings become more vital. Hence, knowledge about human reactions and behaviour towards robots in complex environments, and the influence of robots on the environment with which they interact, is essential. Robots are entering diverse social arenas, while most of the existing research within the field of human–robot interaction, which forms the basic understanding of how people interact and engage with robot technology, is concerned with controlled robot settings such as laboratories and industrial environments. There is a lack of research investigating how robots affect the uncontrolled environments in which they are deployed and therefore a lack of insights into what to expect when humans and robots cooperate in complicated environments and real-life work settings, such as hospitals. As a consequence, hospital staff tend to have greater expectations of robots than the robots are able to meet in practice. Hence, understanding

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the nuances and complexities of how humans and robots interact in hospitals (environments that are not highly structured, controlled or designed for robots originally developed to engage in industrial settings) is valuable for designing future human–robot cooperation-friendly hospital environments focused on socio-technical factors.

This paper reports findings from an ethnographic inspired study of hospital staff cooperating with mobile service robots in a hospital basement. The paper shows how challenges occur in human–robot teamwork in a hospital environment that is not designed for mobile robots, highlighting the socio-technical factors relevant to the robots' impact on the context of which they are a part. Mobile service robots were installed in the hospital basement to improve the physical wellbeing of a specific group of human service workers—hospital kitchen staff—by carrying out demanding physical tasks, such as transporting heavy cargo between destinations in the hospital basement.

2. Background

Related work within the field (mobile robots among humans in everyday environments) has researched how mobile robots affect the environments in which they are deployed. It has been known for some time that robots can change routines, affect activities and influence responsibilities; for example, Forlizzi researched the social impacts of mobile robots in homes and found that robotic vacuum cleaners could change peoples' cleaning activities and routines, influencing who held the responsibility for a household's cleaning tasks. In addition, the robot affected the nature of these tasks—not least the home ecosystem—as the social and cultural context of the home was modified by the presence and assistance of the robot [1]. Robots affect and impact the environment of which they are a part, which was also demonstrated in early work by Sung et al., who argued that domestic mobile robots could change household routines and established how techno-enthusiasts tended to assign names, identities or/and personalities to their robots, leading to acceptance of domestic robots and emotional attachment to the technology [2].

When concentrating on mobile robots in work settings it becomes clear that a number of researchers have attempted to better understand the consequences of deploying mobile robots in dynamic work environments. Their research has shown how human perceptions of robots differ on account of the working environment and how the composition of those environments influence how humans use and experience robots. Early research by Mutlu and Forlizzi (2008) examined how different staff groups within a hospital perceived the same mobile service robot differently depending on different levels of acceptance of disturbances within their working environments across hospital wards [3]. Ljungblad et al. researched the reactions of hospital staff towards a mobile service robot in a hospital and proposed four different perspectives that staff might take in perceiving a robot, respectively an alien, a machine, a worker and a work partner. These perspectives can change over time, such as if a person develops a closer working relationship with the robot [4]. The recognition that robots affect the environments in which they are deployed laid the groundwork for our research, which investigated how robots impact the environment and what to expect when they are released into the wild.

3. Methods

This study researched human–robot interaction and cooperation in a real-life work setting—a medium-sized hospital in Denmark—through an ethnographic inspired field study. In 2016, the hospital installed MiR Hook 100™ mobile service robots to relieve the hospital kitchen staff of the physically demanding task of transporting large carts with cutlery through the hospital basement. The basement is characterised as an unstructured real-life environment with mixed traffic made up of patients, clinicians, laboratory technicians, kitchen staff, porters, technical staff and workmen.

The ethnographic inspired field study, carried out in May 2020, consisted of 26 interviews with hospital employees (16 of whom were kitchen staff) recruited through snowball sampling with the aim of exploring their everyday practices and perceptions of working with the mobile service robots [5]. The study also included observations of two mobile robots performing their daily routines and tasks, operating without—and cooperating with—humans in the basement [6]. Finally, the kitchen staff took the First Author on guided tours during which they described their tasks and routines and explained how the robots were, or were not, involved in these [7][8]. The aim of mixing methods for data collection was to explore the setting; gain understanding of robots in the hospital; investigate the cooperation between this type of technology and humans; and to explore if human expectations towards cooperating with robots were concise, considering the robots' impact on the work setting.

The empirical data was in the form of descriptive notes, photos, video clips and audio files (equal to 10 hours of audio). The audio was transcribed and analysed (according to Braun and Clarke's techniques for thematic analysis [9]), along with the photographs, video and field notes. The empirical data was coded using themes identified in the data, which resulted in 64 codes, which were then organized into 12 themes (for an overview of these, see Table 1) that were reviewed to gain an understanding of how the robots affected the human-inhabited real-life work environment.

In this paper, we highlight three key themes in the following section.

Table 1. Overview of themes

Themes identified in the empirical data			
Reliance and trust	Attitude	Perceptions	Environment
Errors	Behaviour	Irritation/frustration	Division of labour
Conflicts	Workarounds	Tempo/pace of work	War stories
Break downs	Hand-overs	Safety	Technique

4. Results

4.1. Adjustments

A primary finding was that the robots had difficulties adjusting to the basement environment and meeting the human expectations of them. The hallways were narrow and not designed for mixed traffic and were therefore divided into two lanes: one for vulnerable users, such as pedestrians and cyclists, and one for heavy users, such as the trucks used by the porters (see Figure 1). It was unclear to the informants in this study whether the robots belonged to the vulnerable or heavy user groups as they were not formally assigned to either lane. In collaboration with the robots' developers, the hospital made changes to the hallway junctions, assigning robot lanes with the inscription MiR (the product name of the robot). These mark-ups were designed to inform people in the basement how the robots would make their way through the junctions, and the hospital expected that the robots would remain in their lanes.

Figure 1. Left: lanes marked for vulnerable and heavy traffic in the hospital cellar hallway. Middle: robot lane marked at a hallway junction. Right: robot driving through a hallway in the hospital basement.

However, this study found that the mobile service robots were unable to adapt to the environmental changes made by humans to ease their routines, such as by failing to drive in the assigned lanes as the humans expected them to. One of the reasons the robots did not use the lanes was that they had to adjust to factors within the hospital basement environment by avoiding porters on trucks, pedestrians, cyclists and items left on the floor. The narrow hallways also brought humans and robots close very close to each other, and if a robot came close to a human, object or item, its sensors would register a potential risk of causing harm, which would immediately make the robot stop what it was doing. These robotic stops would cause frustration and annoyance among the staff, who did not consider that the robots acted as they did in order to avoid harming their surroundings. The humans in the basement were simply unaware that their expectations of seamless, autonomous robot performance were unrealistic in practice.

4.2. Work-arounds

A variety of factors, including the parties' mutual impact, affected human–robot cooperation in the hospital basement. As mentioned above, the environment was not suited to the robots, not least because the hallways could get crowded, such as when humans, who had their own daily paths through the hallways, took up space, hindering the robots in performing their tasks. When the mobile robots drove around the humans and other obstacles in the hallways, they would in turn affect the routines of the workers. The robots drove at a slow pace for safety reasons, and the workers in the basement became increasingly irritated and frustrated at sharing their workspace with the robots, not least because they had expected the robots to seamlessly integrate, for example by adjusting to the pace of the hospital staff. Frustrations developed among both kitchen staff (because the robots disturbed their routines and pace of work and thus reduced performance) and by the porters (who already had a tense relationship with the robots, simply by their presence in the basement).

During the field study, it was observed that eight out of the 16 kitchen staff chose to perform themselves tasks that the robots were supposed to do, because they felt they could not rely on the robots. Only by monitoring the robots on a tablet could the staff be sure where the robots were, but not how (or what) they were doing. Further, the robots caused the workers' pace to slow, such as when taking up space in the hallway, driving around obstacles and not following lanes (often driving in the middle of the hallway), which made the workers unable to get around them and perform their tasks at the pace they wanted to. The workers had to adjust to the robots because the robots did not adjust to take seamless part in the shared work environment.

4.3. Sabotage

It was clear that the porters perceived the robots differently from the kitchen staff. The porters did not approve of the mobile service robots being part of their working environment because they had a large impact on the pace of the porters' working routines as they drove around the hallways at their programmed speed in order to avoid harming their surroundings. The porters also had limited options to get around the robots in the narrow hallways and did not benefit from their presence. Some porters were unwilling to adjust to the robots and would not hesitate to interfere or sabotage them, which resulted in the robots stopping in the performance of their tasks, and it was not uncommon for frustrated workers to turn off the robots, lock them in rooms or pour food into them. The interference and sabotage were a result of the robots affecting the workers' everyday routines. As a consequence, the kitchen staff became frustrated towards both the robots and the porters because they could not rely on the robots to complete their tasks in part due to the porters' actions. The kitchen staff were unable to trust the robots because they knew from experience that errors would eventually occur that would make the robots slow down, abort their missions or simply stop. The kitchen staff could not be sure what type of error (technical or human-triggered) the robots might have encountered, but they repeatedly experienced how the human presence in the basement affected the robots, which they had not expected would be an issue, when the robots were installed. Accordingly, the kitchen staff, who were supposed to benefit from the robots, could not trust them because of the actions of other humans and because they had higher expectations of the robots than the robots were able to meet.

5. Discussion

The findings highlight the importance of considering socio-technical factors when deploying robots to cooperate with humans in hospital environments. One of these factors is the human expectations of the robots: the hospital staff expected the mobile robots to be a 'plug-and-play' solution, integrating seamlessly and aiding in the real-life environment. Our research has shown that human expectations of cooperating with robots in the wild may be greater than the robots can meet because of three dominant factors. First, the environmental preparations made by the hospital and the robot developers were ineffectual, yet resulted in raised hopes and great expectations from the hospital staff in the basement. Second, the robots were sensitive to staff behaviour, which caused frustration among the staff resulting in robots being prevented from performing their tasks. Third, the staff could not rely on the robots to aid in everyday work situations.

Hence, the robots did not adjust to the changes made by the developers and the hospital but rather to factors in the environment, such as human behaviour, without the staff realising it. Because of the nature of these adjustments, the robots did not drive in an advantageous, reliable way, as had been expected when they were installed, because the basement environment was not suited for this type of robot. In the given case, these factors could not necessarily have been predicted in advance of deployment, as the hospital did not test the robots in a pilot implementation. If the hospital had tested the robots prior to installing them, the factors that were results of the dynamics and interactions between the actors (both humans and robots) and their actions, might have been discovered and suitable adjustments could have been made before the final installation of the robots.

The hospital staff would unintentionally leave items (boxes, containers, or components) in the hallways without reflecting on the consequences, as they were unaware of the robots being sensitive to obstacles and unaware that their behaviour would thus have a large impact on the behaviour of the robots. When the robots encountered obstacles that they were unable to avoid, they would simply stop and wait for the obstacle to disappear. This could lead to a robot not completing its tasks but rather simply standing still while running out of power. The hospital staff who were supposed to benefit from the robots therefore did not rely on them to do what they ought to because of the actions of other humans. The aim of deploying the robots in the hospital kitchen was to ease the burden on kitchen staff to perform logistical tasks in a time-efficient manner, but the assistance was shown to be complex as the kitchen staff found themselves becoming caretakers for the robots, despite the robots being deployed to take care of tasks. The intention of the human–robot cooperation in this hospital was that the robots would support and relieve the hospital kitchen staff, but the hospital kitchen staff instead supported and relieved the robots.

The lack of attention to socio-technical factors in deploying and using robots in this hospital was rooted in techno-optimism, great expectations and the opinions of technology enthusiasts who did not consider how to reorganise existing environments, routines and everyday structures. As argued by Blond et al. [10], the use and meaning of robots are created in practice and cannot be designed in advance. When robots move beyond highly structured environments, the visions and expectations of deploying them in real-life settings must be adapted to those settings. The human expectations of robots cannot be met if they are not considered in relation to the environment in which the robots participate.

Therefore, if robots are to succeed in engaging with real-life environments - rather than reflecting the aspirations of techno-enthusiasts who expect robots to be simple, automatic 'plug-and-play' solutions, without considering the robots' requirements, human adaptations and environmental changes - attention must be paid to the practice in which the robots are to participate, including the socio-technical factors.

6. Conclusion

In this paper, we have reported insights from research on how robots affect the real-life environments into which they are gradually moving. The findings showed that the cooperation between humans and robots in the hospital environment was fragmented because of limited attention having been paid to socio-technical factors. Knowledge of real-life environmental factors; human reactions and behaviour towards robots in complex environments not designed for robots; and robotic influences on the environment in which they act has been summarised, and we have identified three major factors that influence human–robot cooperation in hospitals: environmental factors, behavioural factors and factors related to human reliance on robots.

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Understanding human-robot teamwork in the wild:
The difference between success and failure for mobile robots in hospitals

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Abstract
This paper communicates findings from an ethnographic inspired field study of human-robot teamwork in a hospital, a highly significant topic, as the use of robots has expanded significantly in recent years, and they are being increasingly deployed in naturalistic environments, including hospitals, expected to take part in socio-technical practices and collaborate with humans in teams. The field study took place in a Danish hospital where mobile robots were installed to take on courier tasks and identified two primary human-robot teams in the given setting: one team consisting of the hospital's Technical Manager and the mobile robots and another team consisting of Medical Laboratory Technicians and the mobile robots. The team comprising Medical Laboratory Technicians had a strong dependency on the team encompassing the Technical Manager, in the daily hospital operations. In addition, two main elements affected the teamwork between hospital staff and mobile robots in the given hospital. First, a clear division of responsibility for the robots, including well-defined, simple tasks and instant troubleshooting, was important in ensuring collaborative teamwork. Second, environmental factors were crucial as the hospital setting must be suited for both staff and robots, for the teamwork to succeed. The results were evaluated in comparison to results in a similar, earlier study conducted at another Danish hospital and consequently reveal how a clear division of responsibility for robots and appropriate environmental infrastructure allows for the teamwork between humans and robots to flow satisfactory.

I. INTRODUCTION

Robots are increasingly deployed broader than ever before, not least in naturalistic environments, such as hospitals, where they take part in socio-technical practices and are expected to engage rather seamlessly in collaborative processes and teams with humans [1]. Ideally, the human and the robot are to become co-workers and reach a level where they trust and depend on each other. As trust derives from the human understanding the robot's capabilities and limitations, the human trust in the robot increases, as the perceived understanding of the robot develops [2, 3, 4, 5]. When humans and robots collaborate to achieve a common goal, it is characterized as human-robot teamwork. This involves collaborative efforts between humans and robots, and comprises task allocation, communication, trust, adaptability, and safety. Task allocation involves dividing tasks based on strengths and constraints to optimize performance. Effective communication allows the robot to provide feedback and the human to provide instructions. Trust is established through reliable performance and appropriate feedback. Adaptability is necessary to adjust to rapidly changing requirements, and safety is a priority in high-risk environments. Human-robot teams can perform a wide variety of tasks, depending on the context and the type of robot, for example are mobile robots used to deliver medications, samples or items and to perform routine tasks, in collaboration with human staff [22, 23, 24].

The research communicated in this paper, is situated in a real-life environment in a hospital in Denmark, exploring human-robot teamwork between hospital staff and mobile robots *in the wild*, in an unstructured, complex environment. Such environment can be characterised by lacking explicit rules, guidelines, or expectations and by a high degree of unpredictability and uncertainty. An unstructured environment can be challenging to navigate in and may require individuals to rely on their own judgment, creativity, and problem-solving skills to adapt and succeed: skills that are yet beyond the capabilities of the robots deployed in hospitals [18, 19, 20, 21]. Therefore, it is crucial to investigate the dynamics of the teamwork between humans and robots in the wild, not least as robots are being deployed to a greater extent than before, in real life settings. Understanding the collaboration between robots and humans is important to ensure appropriate development, implementation, and use of robots. For example, it is central to understand how hospital staff and mobile robots are working together, if we want robots to take part in the logistic tasks in hospitals. There is a need for understanding what the parties do, when they do what they do – in order to delegate work, coordinate and organize tasks and thereby ensure both humans and robots the best possible conditions for teamwork, collaboration and co-existence.

The research approach we take on is phenomenological, aiming at understanding the teamwork between hospital staff and mobile robots and gain a detailed, rich understanding of their perceptions and experiences of collaborating. We seek to investigate the teamwork between hospital staff and mobile robots in a Danish hospital (Hospital O) by outlining empirical findings from an ethnographic inspired case study, which will be discussed by including an identical empirical study of the collaboration between hospital staff and mobile robots in another hospital in Denmark (Hospital S). The two hospitals have deployed mobile robots with similar aims

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(relieving staff from pulling heavy carts and increase efficiency by letting robots take on time-consuming transport of carts as part of logistic processes), yet the daily functioning, task performance and outcomes are dissimilar. The phenomenological approach used in this study allowed for a deeper understanding of the field, the robots, the dynamics and the staff's subjective experiences of working with mobile robots in the hospital setting, which provided a more complete picture of the collaboration between human staff and mobile robots in hospitals. The study contributes with a clarification of crucial factors to consider, if humans and robots are to successfully collaborate in a real-life setting, fulfilling the aim with which they are teamed up. These factors are respectively a clear division of responsibility and environmental dynamics, which will be outlined through this paper.

II. Background

A. The need for robots in hospitals

Robots are deployed in various healthcare settings and broadly represented in hospitals. The hypothesized effect of deploying robots in hospitals is that robots hold the potential to aid in a wide range of vital areas, in a sector under pressure. The shortage of medical staff combined with an increasingly heavier and more complex patient load, such as increasing numbers of chronically ill and multimorbid patients, hitherto, and the demographic development in western population in general, will constrain the hospital sector in several ways [6]. Not least will it change the nature of work and workloads, as fewer employees will have to take on more and heavier tasks. Therefore, robots are increasingly engaging in teamwork with humans, to aid and support them, in their work activities. Teamwork between hospital staff and robots is complex, both from a robotic (in this case mobile service robots) and a human point of view. As hospital environments are inhabited by various types of humans, each with varying reasons for being in the hospital (worker/patient/relative), own agendas and pace of walking, the environment can be characterized as unpredictable, and complicated for mobile service robots to navigate in, as opposed to structured, predictable environments such as laboratories and factory settings, where robots have traditionally functioned. In this study, mobile robots are focal [7].

B. Mobile robots in hospitals

Mobile robots are widely installed in hospitals as they can perform tasks on behalf of humans and take part in close collaboration with various types of workers. They can take on simple tasks, allowing hospital staff to perform more complex work, assist and relief staff in their daily routines, supplement understaffing, reduce workloads and optimize workflows [8, 9]. The majority of mobile robots deployed in hospitals are service robots; assistive systems and machines that can carry out a series of actions and are qualified of autonomous decision making, based on the inputs they receive from their sensors, cameras, and microphones, which make them capable of adapting to the situation [10]. Mobile robots can navigate in environments and respond to these in terms of reacting flexibly to the varying conditions they take part in, for example by detecting obstacles and avoiding them. One of the most fulfilling tasks for mobile robots in hospitals, is transportation of items, as they can carry supplies and support logistics, relieve staff and reduce human errors. The use of mobile service robots in hospitals can free staff from certain time-consuming tasks and instead allow them to focus on other responsibilities. Mobile service robots can deliver samples, meals, linen, medicines, medical supplies and packages, with little need for human assistance and can change hospital logistics by taking over delivery tasks that – for humans – are delimited by for example time. Deliveries can thereby become more efficient and flexible instead of being bound to fit into human workers' schedules. In addition, they can perform repetitive routine tasks, increase effectiveness, and ensure consistency and homogeneousness in task performance [11, 30].

C. Case: Robots in a Danish hospital

In 2021, we analysed human–robot cooperation and interaction in the basement of a minor Danish hospital, where kitchen staff and porters conducted their daily work routines in an environment shared with mobile robots, as communicated in [16]. The robots were installed to ease the everyday routines of kitchen staff and carry out physically demanding tasks, such as transporting heavy cargo between destinations in the hospital basement. However, the cooperation between humans and robots in the hospital environment was fragmented, as limited attention had been paid to socio-technical factors, not least the staffs' expectations of cooperating with robots in the wild, were greater than the robots could meet, due to three dominant factors: environment; staff behaviour and; factors related to human reliance on robots. This resulted in robotic errors which frustrated staff; lack of human reliance in the robots and thereby lack of collaboration; and sabotage. Consequently, the robots could not live up to the aim of relieving staff and increasing efficiency.

These findings from Hospital S reveal the need to investigate human-robot collaboration and teamwork further, which the study communicated in present paper contributes to, by scrutinizing the field at another site, Hospital O.

D. Research in the wild

When researching the teamwork between hospital staff and mobile robots, both at Hospital S and Hospital O, the robots are situated in naturalistic settings and in the context of socio-technical practice. Hence the collaboration and teamwork are investigated through a Research in the Wild (RITW) approach. RITW refers to how, what and where research is conducted in naturalistic settings and the goal is to understand how technology (in this case robots) operates and can be used in the real world [25]. This understanding can be used for gaining new insights about how to engage people in activities concerning the technology, about how peoples' lives are impacted by a technology and what people do, when encountering a (new) technology in a given setting. In the case of this study, RITW can be used for gaining insights on the teamwork between hospital staff and mobile robots. Further, it can explore assumptions, investigate how hospital staff react, change, and integrate robots in relation to their work, both in terms of culture and tasks [12]. When doing research in the wild, the importance is placed on settings and contexts, in this case the hospital where humans and robots are collaborating, which can reveal the kinds of challenges they face and demonstrate staff behaviour. This enables the researcher to explore how a range of factors can influence the teamwork between humans and robots [12]. Traditionally, robots have been deployed, developed and tested in laboratories and there is a strong tradition to test robots in synthetic environments that also include digital or virtual environments. One of the benefits of RITW studies is that they have high ecological validity as they are settled in everyday life settings, whereas laboratory studies may be more artificial or contrived. Laboratory studies however, have a high degree of experimental control and structure, allowing the researchers to focus on specific variables to investigate and potentially achieve greater precision and accuracy in their measurements. Nevertheless, there seems to be a mismatch between how robots are used in laboratory and virtual settings and how they are interacted with and approached in different real life situations, for example when human workers and mobile robots are collaborating in hospitals, because the contextual factors, that are difficult to replicate in the laboratory (such as social norms, cultural expectations, and environmental factors) suddenly plays a role [12, 25]. Further, more contextual studies are required within the field of human-robot collaboration, to understand how people and robots collaborate in varying arenas, situations and cultures [31]. The methods used in this study for understanding how robots and humans are collaborating in a real-world setting, is outlined below.

III. Methods

This study researched human–robot teamwork (including human-robot cooperation and collaboration) in the wild, at a large hospital in Denmark, through an ethnographic inspired field study, carried out late November 2022. The hospital is chosen as it has a unique focus on robots and have recently inaugurated a centre for researching and innovating clinical robots.

A. The hospital and the Hubots

Odense University Hospital, OUH, is one of the four university hospitals in Denmark, collaborating with the University of Southern Denmark. OUH has approximately 11,000 employees across its operational region and is specialized in treating a range of complicated illnesses and therefore also treats patients from the rest of Denmark, and in some cases from abroad for example heart and vascular diseases, cancer and replantation of fingers, hands etc. Consequently, there is a varied mix of humans in the hospital.

The hospital had installed a range of robots for transporting various items around the hospital. This research focused on two autonomous mobile robots (AMRs) for carrying blood samples around the hospital. The two mobile service robots operated on the ground floor and 1st floor. The two robots were named respectively Hubot and Hubot2. The name Hubot2 was a direct consequence of this robot being deployed after Hubot. In daily routine, the hospital staff had nicknamed Hubot *Big Hubot* and Hubot2 *Little Hubot* or *Mini Hubot*.

Figure 1. Hubot and Hubot2 standing next to each other in the Laboratory

Figure 2. Left: A look inside Hubots' cabinet. Right: The handle, lock and smartphone attached to Hubot

The robots were based on the MiR 200, an autonomous mobile robot, developed for industrial use. They were equipped with scanners and cameras, allowing them to operate and navigate around people and objects on the way. Besides the MiR200 mobile base, the Hubots were built by the TM at the hospital, who created the Hubots from bits, pieces and stuff he had in stock in his office/robot garage. The Hubots both have a cabinet on top, in which blood samples are stored while the robots drive. In Hubot there are three baskets inside the cabinet, while Hubot2 has one single box for storing blood sample racks inside its cabinet . Both Hubots have a lock, an emergency stop button and a smartphone attached to it, from which the hospital staff can lock/unlock the robots, stop them, and send them on missions. For an extracted example of how a morning in Hubot's day looks, see Figure 3. The figure illustrates what Hubot does, starting its day at 5 o'clock driving from its docking station in the Hospital Laboratory onto the Intensive Care Unit, to collect samples, driving down to the laboratory to deliver them, before being sent off on yet another mission.

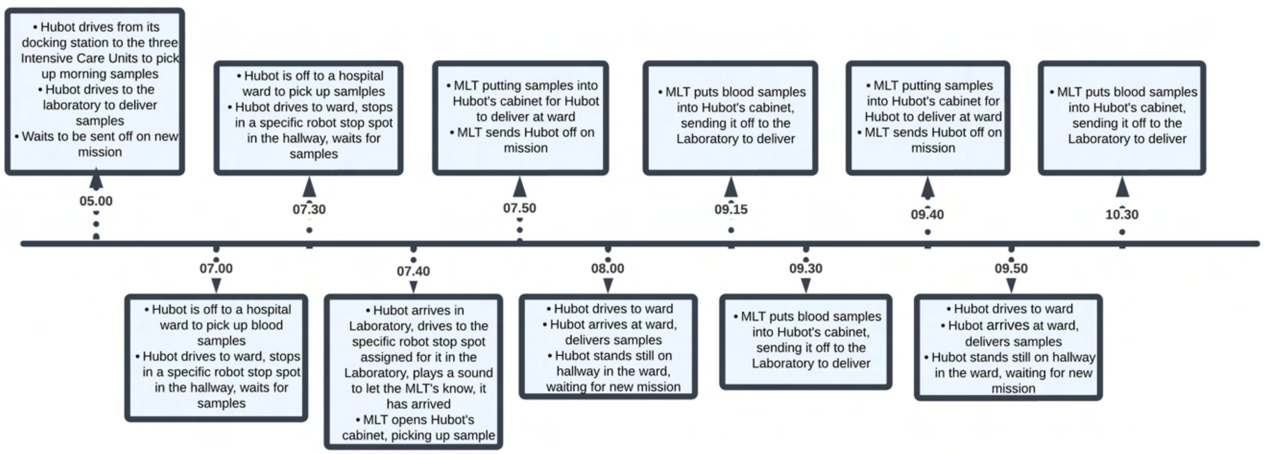

Figure 3. A timeline providing a simple example of what Hubot does in one morning

This pattern repeats throughout the day, ending at 16 o'clock, where Hubot yet again drives into its docking station, recharging for a new day.

The robots were deployed to take on courier processes and transport blood samples around the hospital. Figure 4 provides an overview of the ground floor of the hospital and the lines shows the robot routes.

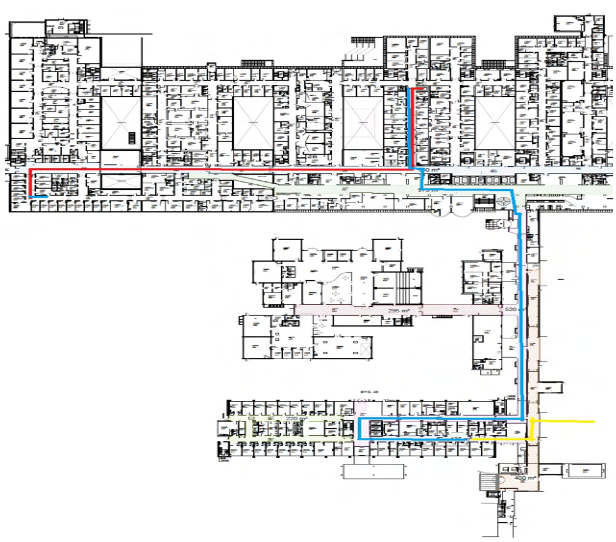

Figure 4. Overview of the robot routes in ground floor of the hospital

The red line represents the route Hubot drives, while the blue line represents the route Hubot2 runs. Hubot is relieving staff from walking approximately 8 kilometers, 2.5 hours, with blood samples, every day. The robot picks up blood samples in a clinical ward at the first floor and drives them down to the laboratory in the hospital ground floor. Hubot2 is picking up blood samples in the Children's' Clinic at the first floor and driving them down to the laboratory in the hospital ground floor. In the hallways, there are certain robot stop spots, where the robots will park and wait to be interacted with. There is a low level of conflict between the two robots, as they share minimum of route: the hallway where the elevator is situated and the laboratory is the only place in the hospital, the robots are sharing. To get between the floors, the robots are using an elevator, which they share with the staff. To occupy the elevator, the robots drive in front of the elevator and wait until there has been no activity for 15 seconds. Only then, the robot takes control of the elevator. Consequently, the robots may have to wait a long time for the elevators because the staff uses them frequently. Once a robot has taken control of the elevator, a human cannot control it, but must wait for the robot to finish its ride or ride along. However, the robot parks in the centre of the elevator, leaving a minimum of space for a human to fit into.

B. Data collection

The empirical data collection was characterized as a mixed methods approach, consisting of observations, interviews and guided tours. Participant observation comprised the backbone of the data collection and was utilized to gather data, information and insights on the teamwork between staff and robots. The participant observations were conducted by FA who followed the two *Hubots* around the hospital, as they performed their daily missions and interacted with surroundings, hereunder staff members [13]. The empirical data was brought home in the form of thick descriptive field notes, photos, audio clips (equal to 8 hours of audio) and video recordings, produced in the hospital, contemporaneously with the phenomena, events, experiences, and interactions, they describe. Further, data was collected through 20 short on-site in-situ interviews with Medical Laboratory Technologists (MLT's) who were the ones collaborating with the Hubots. The interviews provided a mean to gain a deep understanding of the meaning of participants' experiences and point of views, which was essential for gaining a comprehensive understanding of the teamwork between staff and robots, which was necessary to understand the significance of collaboration, routines and work practices [26, 27, 28, 29].

Finally, data was collected through guided tours around the hospital and expert interview with the technical manager (TM) at the hospital [14]. He was the one who had built - and held responsibility for - the Hubots. The empirical data was transcribed and analysed according to Braun and Clarke's techniques for thematic analysis, along with the photographs, video and field notes [15]. The data was coded using themes identified in the data, then organized and reviewed to gain an understanding of the teamwork between hospital staff and the Hubots. The results from the study are outlined in the next section.

IV. RESULTS

Throughout the field study it became clear that the robots spent a lot of time standing in the hallways of the hospital, waiting to be interacted with. It was observed how hospital staff performed their tasks, such as taking blood samples from patients, and after having done so for varying periods of time, they would eventually approach the robot waiting in the hallway, load it with blood samples and send it off to delivery in the laboratory. The robots would stand in the hallways for 20 minutes in average, waiting to be loaded. In that time, they stood unnoticed for the personnel, who did not pay attention to the robots. For the TM, it was crucial that the robots operated unnoticed, he expressed that they should not be distinctive or irritating, because that would lead to frustrations and difficulties.

A. Human-robot teams

The robots were part of different teams, including two main teams: The first team consisted of the Hubots and the Technical Manager (this team will be referred to as Team HTM), the second team was the Hubots and the Medical Laboratory Technologists (this team will be referred to as Team HMLT). Team HMLT is dependent on Team HTM, as the robots are being supported by the TM, who is dedicated to ensuring that the robots are running without problems. In Team HTM, the robots were the ones being supported and aided by a human, while in Team HMLT, the robots were the ones supporting and aiding humans. Thereby, Team HMLT was dependent on Team HTM: if the TM did not support the robots, the robots would not be able to perform its tasks and thereby support the humans on Team HMLT.
The teams are characterized below.

<u>Team HTM</u>

The team consisting of Hubots and the Technical Manager (Team HTM) is characterized by being paternalistic: The TM is caretaker for the robots and holds a deep, broad knowledge and understanding of the robots and has been teaming up with them since before they were implemented at the hospital. He has partly built them and gradually programmed, adjusted and refined the robots to fit the hospital environment and the humans around them. The TM is constantly on the lookout for the Hubots and tailors tasks, maps, and other technicalities, for the Hubots to function in the best possible manner. He has several ways to monitor the Hubots, both on tablets, smartphones and via his computer, providing him with overview, which makes him capable of following the robots in real time and able to detect errors. The TM has a rule: if difficulties or errors occur, it must not take him longer than 5 minutes from the error detection, for him to begin troubleshooting. His mantra is, and has been since the robots were built, that the robots must not be irritating, because that will ruin every piece of goodwill the hospital staff have with the robots: and if that is ruined, the robots will become a source of frustration and anger. He states: *If a robot suddenly stops, everything around it will stop as well. Therefore, if you have mobile robots in your hospital, you MUST have someone onsite who is dedicated and can take care of the robot as soon as something happens to them. And it must of course be someone who really takes it seriously. If not, the staff will be like 'oh these things never work', 'robots mess up our routines' and then they will have to call someone outside the hospital to get support. Which no one has time for – and then staff will just let the robots stand still, not use it and talk bad about it. That must not happen. And it never will happen, on my watch.* The TM utilizes a range of tools, also accessible externally, to monitor the robots. Consequently, the downtime is very low and often, the hospital staff doesn't realize that there has been something wrong with the robots before the TM has already fixed it. The TM has programmed the robots to *care*, he states: *they must not stand in the way for people*. The TM has also voiced and given sounds to the robots – for example, the robots articulate *Please step aside, Keep to your right when you walk the hallways, Samples have arrived* when they drive around in the hospital, in the voice of the TM. The hospital staff knows that he is the one to call, if they have difficulties with the robots, he is well-known around the hospital as *the one in charge of the robots* and is the one who have trained the hospital staff to use the robots. He addresses the robots *they* and *it*, neuter, and has a neutral and objective bond to the robots.

<u>Team HMLT</u>

The team consisting of Hubots and the Medical Laboratory Technologists (HMLT) is characterized by the robots being an aid and *helping hand* throughout the MLT's day. The MLT's state that it is of minor importance to them, if the blood samples are delivered by robots, by human service staff or via pipe systems in the wall, the important thing is just that they receive the samples. However, the MLT's find that the robots can deliver the samples faster than calling service staff – and it is easy to use the Hubots, because it only demands a bit of clicking on a smartphone: MLT1: *I think it is so easy to collaborate with Hubot! It is straight-forward and there is nothing that you must stand and think about anything for a long time.* One of the MLT's state that the hospital service staff already are busy, so it is better to use Hubots than to overburden the service staff group. The MLT's consider the Hubots as a supporting tool, but address both as he and him, which they are fully aware of, when asked: MLT2: *Hubot is definitely a 'he'.*The MLT's personalize the robots which bears witness that they consider the robots more nuanced than just a tool, but rather colleagues, to some extent: MLT3*: I definitely think of Little Hubot and Big Hubot as tools helping* *us! Absolutely. But.. But then again.. Yeah, actually, I talk to them as if they are my colleagues..* Some of the MLT's seems to have a close relationship to especially Hubot and seems to care about the robots' well-being: *MLT2: Sometimes, there seems to be problems with Hubot and the elevator. It happens that people ride the elevator together with him and then rides up to a floor that Hubot doesn't know his ways around. Then, when he drives out of the elevator up there, out to a place he doesn't know, then he gets confused.* The HMLT team's relation to the Hubots is indirectly influenced by the HTM team, as the MLT's are personalizing the robots and interpreting them and their actions, programmed by the TM. For example, the TM have programmed the robots to stop when they get too close to a human. This is interpreted by the MLT's as politeness: *MLT2: Hubot, he would never drive into one of us. He knows us, he wouldn't be rude like that!*. But the Hubots doesn't hold any social intelligence, their actions and responses are simply coded and programmed by the TM. The MLT states that they are the ones to bump into the robots: MLT2: *It is rather us who tends to bump into him when he drives around, because we are so use to him that we're not always conscious of where he is.* MLT4: *Hubot and Little Hubot, they never bump into us. It is rather us who bumps into them, by accident of course, because we don't pay attention to them, as we are just used to them being here, around us.*

The MLT's find the Hubots helpful and part of them state that the Hubots are relieving them from annoying tasks: *I think that Hubot is someone who can do all the annoying slave work* while another MLT state that: *I think it is very nice to collaborate with the robots.* They only experience problems with the robots in relation to the elevator. The robots and the hospital staff share one elevator and the robots take, from the MLT's points of view, a long time to ride the elevators, which can cause bottleneck and slow down their work. When asked, the MLT's expressed that they perceived the Hubots as something in-between a tool and a colleague; something or someone to reliably take on all the annoying, strenuous tasks and complete them.

<u>Minor teams</u>

Besides from the HTM and the HMLT teams, there is also another, rather invisible and informal team: the Hubots and the cleaning lady in the ambulatory, who tends to notify the ambulatory staff that the Hubots have arrived. This surfaces through following scenario, experienced by FA, during data collection: Hubot arrives at the Ambulatory with blood samples. When the robot has parked, it plays a sound saying *Samples have arrived. Samples have arrived.* But no one responds. The hall is empty for MLT's and so is the office that Hubot has parked outside. I get eye contact with the only person in the hallway, the cleaning lady. She comes over to me (I stand next to Hubot) and tell me that the personnel has probably left for lunch. She manages to find a MLT who goes to Hubot and takes out the samples it has been carrying. *Thank you, Hubot,* she says. Then she looks at me, smile and says *Yeah, he is very easy to deal with.* She walks on. The cleaning lady looks at me and says *He is. But we always have to keep an eye on him and help him.* And it seems that this is not the first time, she has notified the MLT's that Hubot has arrived for them. Just as the cleaning lady had said that, another MLT comes around and says *Yes, but it is because Hubot is a typical man!* while she laughs. The Hubots are perceived as male and, to some extent, ascribed stereotypical male characteristics and qualities.

B. An environment suited for robots

A primary finding in this study was that the environment shared by robots and humans were well-suited for this. The robots managed to perform their tasks because they were implemented into an environment geared for mobile robots, for example the hallways were broad and there were no heavy trafficants in the areas where the robots were driving.

The spaces in which the robots drive are wide and open and consequently the robots are able to navigate around obstacles and humans. The TM stated *It will never work, to have robots in a place like this* in regards to certain areas in the hospital, such as narrow hallways in the basement, where service staff are driving around in large, fast speeding trucks, carts and beds are taking up great amounts of space, and there are bicycles and other types traffic. The hospital basement was simply not geared to have robots driving around, instead, they drive on the ground, first and second floor, where the hallways are wider.

V. DISCUSSION

This research found that especially two main elements affect the teamwork between humans and robots in the given hospital. The first element is clear division of responsibility for the robots, including well-defined, simple tasks and instant troubleshooting. The second is environmental factors.

In the following, these elements are discussed by including an identical empirical study of human-robot collaboration in another hospital, where two mobile robots are deployed to support hospital kitchen staff by delivering objects between spots in a hospital basement [16, 17]. In the following, the two hospitals will be identified as Hospital O and Hospital S.

A. Division of responsibility (incl troubleshooting)

In Hospital S there were no guidelines or descriptions of the work practice between staff and robots and consequently it was difficult for staff to navigate in the delegation and coordination of tasks between them and robots.

In Hospital O, there was a clear, simple division of tasks delegated to the robots and as a result, the staff, the MLT's, did not have to consider coordination nor delegation of tasks. In Hospital S, the responsibility for the robots was not assigned to anyone in particular: everyone was responsible for the robots, including troubleshooting in case of errors (which happened often), despite them not having received any training. In Hospital O, the responsibility for the robots was completely on the shoulders on the TM and every staff member knew it, which made troubleshooting in case of errors simple: if the TM was not already working on the issue, staff members would simply call him. In Hospital S, the kitchen staff spent a great amount of time helping the robots perform the tasks they sent them off to complete. Consequently, the robots were perceived as complicated time-consuming sources of extra work, rather than aiding and supporting. Thus, part of the hospital kitchen staff refused to work with the robots and rather performed extra work and tasks themselves. Others, who collaborated with the robots, tended to follow the robots around when they were sent off to perform tasks, to ensure their performance. The robots thereby effectively increased the staffs' workload and decreased the overall efficiency.

In Hospital O, the staff members collaborating with the robots, the MLT's, considered the robots as helping hands aiding and supporting their work processes. They find it very easy to work with the robots and often they don't notice the robots are around, because they are not in the way, irritating or distinctive. The MLT's do not hold the responsibility for the robots, do not have to help the robots perform nor fix errors, which is the core reason they find it easy to collaborate with the robots: it is simple, and it works. The MLT's can trust that the robots will perform the tasks they are sent off to do – and they know that the TM will make sure that errors are fixed. The TM thereby works as a safety net for the HMLT team, who depends on him.

B. *Environment affecting human-robot teamwork*

As mentioned above, Hospital O has installed robots to drive in wide, open spaces. The opposite is the case in Hospital S, where robots are installed to operate in the hospital basement with narrow hallways and heavy traffic such as porters on large, fast speeding trucks. In both cases, the robots are installed in spaces where humans are walking.

The narrow hallways in Hospital S brought robots and humans very close to each other which made the robots stop due to the inbuilt safety mechanism (to not cause harm to humans). The robots would also stop if they came close to other obstacles, such as boxes or other objects left in the hallways. The robots did not necessarily start again, but stood still in the hallways, blocking for passage, making traffic in the basement difficult. In these cases, hospital staff would have to restart the robots – but since the responsibility for the robots was liquid, no one was assigned to take care of the robots, when incidents like this occurred. This meant that the robots often just stood still in the hallways, blocking passage. The robots took up a great amount of space which affected the work of the hospital staff, who became increasingly frustrated and irritated by having the robots as part of their work environment. Further, the robots drove in a slow pace and the porters were unable to get around them on their trucks. Consequently, the porters would have to drive behind the robots and adjust to their pace, slowing down their speed, resulting in them not being able to perform their tasks. This led to frustrations among the porters, who – in some cases – would sabotage the robots and the kitchen staff, who were to benefit from the robots, were unable to trust the robots to perform the tasks assigned to them. Therefore, the teamwork between staff and robots in Hospital S was vague and difficult.

As seen throughout this paper, Hospital O had installed their robots to drive in wide, open spaces and with outset in the mantra that the robots must not be irritating. Consequently, the robots in Hospital O drive around without much notice and supported staff, who trusted the robots to perform the tasks assigned to them, making the teamwork between staff and robots valuable.

VI. Conclusion

The findings of this research have revealed the importance of clear division of responsibility for robots and appropriate environmental infrastructure when humans and robots are teaming up in work situations in the wild – in this case in hospitals.

It is important that the responsibility for the robots is assigned to someone onsite who is dedicated to support and troubleshoot the robots, for the robots to be able to support humans. If there is no safety net underneath the robots, such as an engaged technical manager, it can lead to frustrations and anger among the hospital staff, who are teamed up with the robots. Further, it is crucial that the tasks are clearly defined and distributed among humans and robots, so no one is in doubt when (or whether) to use the robots. When the vital infrastructure is in place, humans collaborating with robots can find the surplus energy to ascribe the robots particular qualities and characteristics and personalize them, which develops the relationship and teamwork between the parties, making the bond between humans and robots stronger.

This research has also identified that the environment must be suited for both humans and robots, for the teamwork to succeed. For example, if the hallways are narrow, it can cause difficulties for both humans and robots to perform their tasks when sharing space – which can lead to frustrations and sabotage. If the settings are well-suited for both parties, the teamwork will flow well.

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