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Working with Bounded Collaboration: A Qualitative Study on How Collaboration is Co-Constructed around Collaborative Robots in Industry

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We investigate how collaboration is understood and configured in industrial workplaces with collaborative robots (cobots). Through a qualitative analysis of 115 case studies of companies using cobots and 14 semi-structured interviews with cobot manufacturers and users, we examine the usages of cobots in the manufacturing industry over the entire temporal spectrum from pre-introduction to completed implementation. By synthesizing diverse stakeholders' perspectives, we present a set of main findings; key roles of a few supportive production workers during the adoption of cobots; a fragmentation of work tasks and the resulting loss of job identity among workers; the disunified meaning of "collaboration" which is under constant development; and the collaborative space and the working rhythms between production workers and cobots. By reconsidering what collaboration means in the workplace with cobots, we propose the concept of *bounded collaboration*, which means that the anticipated collaboration is manifested in a partial and limited manner within a collaborative technology. Finally, we provide practical suggestions for examining and supporting organizations and users in their adoption of cobots.

CCS Concepts: • **Human-centered computing → Collaborative and social computing devices**; **Computer supported cooperative work**; *Ethnographic studies.*

Additional Key Words and Phrases: Collaborative robots, Cobots, Bounded collaboration, Manufacturing industry, the Future of work

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1 INTRODUCTION

Robots have been successfully deployed in various industries, from automotive to pharmaceutical. Their recent proliferation is rapidly expanding into other industries and workplaces [24] e.g., hospitals [82, 84], construction sites [22, 88], public spaces, and offices [34, 64, 81]. Robots have changed the nature of work as well as transformed the roles of human workers, requiring us to rethink the relationship between robots and human workers. Our design of the future of work should conform not only to the expected roles of robots but also to workplace protocols. In particular, identifying expectations and adoption of these emerging technologies by diverse stakeholders

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(e.g., manufacturing robot developers and human workers on production floors) will be critical to developing desirable future work arrangements.

Among the surge in robotization in various workplaces, one of the fastest-growing sectors is industrial robots [31], e.g., those used in car manufacturing, soldering, palletizing, and various other tasks. Next to classical industrial robots, collaborative robotic solutions such as collaborative robots (cobots) have begun to be embraced in industrial settings, attracting attention from governments, other industries, and academia.

While the term *collaborative robot* (cobot) seems self-explanatory in implying collaboration between humans and robots, the meaning and appearance of human collaboration with robots is not exactly clear. The ISO definition (ISO/TS 15066), which was in development for several years before reaching a formalized definition of what characterizes a cobot, focuses quite heavily on safety aspects, such as constraints on operating speed and pressure. These criteria are defined in order to guarantee that no real harm can come to a human were they to collide with a cobot. This low-risk operation makes it possible to move and work in close proximity to cobots, thereby removing the need to house cobots in protective cages. While the ISO standard focuses on safety, alternative definitions exist. According to the National Robotics Initiative (NRI) 2.0 program [31], the definition of cobots was recently updated as "a robot whose main purpose is to work with people or other robots to accomplish a goal. An ideal co-robot is an adaptable partner, not limited to a narrow set of specified interactions or functions, but able to significantly enhance team performance despite changes in its role, its teammates, or the team's collective goals." As the ISO and NRI shared in their definitions, collaborative robots have several advantages over classical industrial robots, making them more flexible and thereby increasing their relevance to smaller and medium-sized companies.

While industry and academia have promised collaborative robots (cobots) in the workplace in recent years [14, 62, 66, 85], there has been a lack of research on how the diverse actors around cobots perceive their collaboration. For example, in the existing literature (e.g., [49, 76, 88, 89]), we see potential tensions such as a lack of focus on the perspectives of cobot users (e.g., workers on the factory floor) [22, 23, 90]. As in other technologies, there are gaps surrounding the anticipation of collaborative robots and the reality of their adoption and usage in collaborative work in real-world environments. The CSCW community can contribute significantly in identifying and addressing these gaps and investigating the evolving definition of collaboration with new collaborative technologies and processes that influence the nature of work alongside them. These understandings would establish a new agenda and design implications for the future of work with other emerging collaborative technologies.

In this paper, we investigate the impact of collaborative robots on manufacturing work and environments, embracing viewpoints from different stakeholders such as cobot manufacturers and their customers (e.g., company directors, managers, and production workers). We utilized a multitude of data collection methods, including 115 case studies and 14 interviews with various stakeholders, as well as observations during visits to Danish manufacturing companies [1]. To guide our efforts in understanding the impact of new collaborative technologies (i.e., cobots) in a workplace, we investigated the following research questions:

(1) *What are the technological visions that cobot manufacturers reinforce, and how might such visions manifest in the adoption and use of cobots in the manufacturing industry?*

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[1] Danish manufacturing companies were chosen due to their geographical availability to the authors. Additionally, Denmark has been a leader in collaborative robot manufacturing, having established the world's largest collaborative robot hub in the country.

(2) *How do diverse stakeholders of collaborative robots – cobots manufacturers, their customers, including managers and production workers – co-construct the meaning of collaboration and the future of work?*

This study adds to the CSCW community's understanding of collaborative robots (cobots) – a rapidly emerging technology in the workplace– by conducting a qualitative and ethnographic study with a range of stakeholders, such as employees of cobot manufacturers and their customer companies. While examination of new technologies has been one of the major contributions of CSCW literature (e.g., [3, 5]), the investigation of robots in the industrial setting has not received much attention. We detail how the cobots have been incorporated into workplaces, changing perceptions of the end-users (e.g., companies and their employees) on work activities, and disunified meanings of collaborations in semi-automated work. Furthermore, this study contributes with the novel finding of loss of job identity, linked to the fragmentation of manual work. We found that, while the introduction of cobots had a number of benefits, it also posed the risk of them taking over critical aspects of the human workday. While cobots did not completely replace people, they did eliminate the necessity for manual performance of core tasks, relegating workers to the role of "robot supporter." Lastly, by reconsidering what collaboration means in the workplace with cobots, we propose the concept of "bounded collaboration," which means that the anticipated collaboration is manifested in a partial and limited manner within a collaborative technology.

2 RELATED WORK

In this section, building upon existing works of CSCW and human-robot collaboration (HRC) studies, we first present research on robots in the current industrial settings, with focus on the manufacturing industry, and the different perceptions of human workers towards the robots. We also show a body of research investigating human workers' relationship to robots in other workplaces. Lastly, we present existing collaboration models and frameworks attempting to classify and categorize different types of interaction with collaborative robots.

2.1 Robots in the Manufacturing Industry

A body of research has examined robots interacting with human workers in the manufacturing industry (e.g., [25, 50, 51, 66, 76, 92]). Various stages of acceptance and use of industrial robots and cobots were discussed. Topics discussed include motivations of adopting cobots [22], the impact of robot introduction [76], integration process of cobots into work routines [51], different relations to the robots on the production floor depending on employees' positions [20, 61, 66, 73], and users experiential aspects (e.g., challenges and opportunities) of interacting with robots in the factory [88, 94].

The decision for a company to invest and integrate collaborative robots in the workplace is quite nuanced and comes with a multitude of added benefits and potential areas of concern. Compiling the results from 13 interviews with directors, managers, and supervisors from six different companies, Simões et al. [22] investigated what aspects play a key role in the decision to adopt cobots into the workforce. They identify three main drivers that impact the adoption decision: internal, external, and technological-motivated factors. Across these three categories, some identified factors include value-added perception (managers' belief of additional value creation through the investment), other companies that have had success with cobot implementation, as well as the increase in velocity of production. While this study was conducted with employees with a managerial role, their findings highlight the importance of early involvement of future robot operators [21, 22, 97], in order to make the adoption decision a common interest instead of a decision dictated by management, thereby increasing the acceptance of cobots for all involved parties.

Introducing new technologies in the workplace often results in unexpected changes for employees [2, 14, 83] as well, such as changing their perceptions of their work around technology or creating social and organizational dynamics at work. For example, Smids et al. [76] investigated the impact of robot introduction on workers' perceptions of the meaningfulness of their new tasks (e.g., job satisfaction and challenges). The recent study by Cheon et al. [14] looked at how the introduction of cobots into an organization led to new social interactions between different groups at work.

As the integration of cobots in the factory has been a source of concern for many manufacturing companies (e.g., [66, 76]), researchers [51] investigated how companies integrate cobots into their work routines, based on the interaction readiness model [19]. The authors investigate whether the lower level of technical expertise required to program cobots can lower the barrier to entry into the workforce, thereby reducing the skill gap and employee shortage currently observed in the manufacturing industry. Through interviews with nine representatives of five companies, the authors demystified the cobots as "simply uncaged" robots by illustrating the level of advancement of current cobots. While cobots are marketed as collaborative tools that can work side by side for flexible use cases, they also found that this was rarely the case. Direct interaction with the cobot also was rarely the case. The authors illustrated that the primary use case was low-level collaborations in simple applications, utilizing simple "press start/stop" types of interactions. The flexibility often highlighted as a selling point for cobots was rare, as cobots were used as uncaged industrial robots.

In addition to research focusing on the cobots' introduction and integration processes, a good body of work examined varying perceptions of robots over time at manufacturing workplaces among stakeholders based on the role and positions at the companies [20, 61, 66, 73, 88]. Many studies portrayed only one-sided views, focusing only on managers' [22] or production workers' [14, 50, 88, 94] perspectives, which could be problematic to see how their different views may be conflicted or compromised. For instance, in contrast to Simões et al., who focused on the adoption decision from the managers' point of view, Welfare et al. [88] investigated the assembly-line workers' perception of their potential robot coworkers. They focused on two areas: the human element (e.g., workers' preferences for particular activities) and assembly-line workers' perceptions of technology and robots on the factory floor [50]. According to their findings, the authors suggested that prior to introducing robots into the assembly line, it should be determined which of the workers' tasks, not the managers', appear to be the most relevant for job replacement, as tedious and repetitive tasks may increase personnel willingness to collaborate with the newly introduced technology, such as a cobot. In line with this study [88], research on employees' perceptions on adopting cobots commonly emphasized the importance of worker involvement [14, 21, 22, 88, 97].

Despite the fact that the majority of studies on employee attitudes of robots focus on one-sided parties, a few studies (e.g., [66, 79]) encompassed perspectives from diverse stakeholders around the cobots. For example, in order to get a deeper understanding of the interactions and perceptions of factory workers towards cobots, Sauppé and Mutlu [66] conducted an ethnographic study in three manufacturing facilities by focusing on workers' perceptions towards the anthropomorphic collaborative robot, Baxter. They looked at the relationship between cobots and various positions of employees: management staff and maintenance staff, and daily operators. The authors identified that the anthropomorphization of Baxter (e.g., a tablet with Baxter illustrates eyes, the robot can have "bad days") was only performed by the operators who had direct and frequent interactions with it. The maintenance and management employees still viewed it as a tool/equipment.

Summing up the studies in this section, previous cobot studies in HCI and CSCW discussed only a certain part of the cobot adoption processes, from anticipating the adoption of cobots to experiencing with cobots in everyday work. The comprehensive temporal overviews, e.g., how the cobots were introduced, used, and finally have made influences on work arrangements, was currently missing. In our study, we focused on individual and organizational changes that the cobots have made in workplaces over time and how diverse stakeholders perceive these changes.

2.1.1 Robots in Other Workplaces. Besides the manufacturing factories, human-robot collaboration studies [42, 63, 67, 72] have investigated how human workers work with robots in various settings, mostly in medical or healthcare contexts [12, 48, 56, 82, 84]. They discussed elements that may influence people's attitudes about robots as a result of workplace robot adoption (e.g. [22, 74, 75, 88, 93, 96]). For example, in terms of hospital robots, Ljungblad et al. [48] found that how much workers are familiar and spent time with the robots shaped varying perceptions on the robots, describing them as "alien," "machine," "worker," or "colleague". Similarly, Mutlu and Forlizzi [54] identified that the workload of and emotional demands on the workers were critical factors in embracing the robots. To investigate the change that the workplace might undergo because of the introduction of cobots, they introduced an autonomous delivery robot into a hospital (i.e., in the medical and the post-partum unit). While the staff at the post-partum unit described the unit as starting to depend on the robot and perceived it as very helpful, the medical unit had the opposite experience. The staff in the medical unit perceived that they were helping the robot and not vice-versa. This highlights the critical nature of context in the workplace when deploying collaborative technology. While both units are within a hospital, the context of the task they are completing has a considerable impact on the perceived usefulness of the robot. The post-partum unit is described as a happy, relaxed place and tasks performed here are typically not time-sensitive. On the other hand, the medical unit is a lot more intense and where patients with serious conditions are often treated in a time-sensitive manner. These different degrees of interruptibility make a difference in an autonomous technology's perceived usefulness, like the robot.

While many studies of robots in other workplaces offered good insights on how robots could be integrated into workplaces more smoothly in the future, there is lack of examinations or reflections on how the robots actually have supported or worked with human workers. In this paper, we specifically seek to unfold the collaboration configuration in workplaces by asking how the collaboration between human workers and cobots is currently carried out in the production lines and how such collaborative aspects of the cobots might be perceived and constructed differently over time. In the following section, we take a closer look at models and frameworks that formulated the interaction and collaboration between human and robots.

2.2 Classification of Human-Robot Interaction and Collaboration

A multitude of approaches have been made to categorize different types of human-robot interaction (e.g., [70, 71, 95]) and human-robot collaboration (HRC) (e.g., [10, 19, 86, 87]). Wang et al. [86] conducted a literature-based collection of the existing works of HRC to classify different types and modalities of HRC. The authors set out by defining HRC: *"The main objective of the collaboration is to integrate the best of two worlds: strength, endurance, repeatability and accuracy of the robots with the intuition, flexibility and versatile problem solving and sensory skills of the humans."* [86]. While the quote identifies the target of HRC, they pointed out that more concrete definitions of the different types/categories of human-robot relationships would be needed. Based on six characteristics (physical workspace, the degree of direct contact between human and robot, the task that is attempted, the resources that are used for this, and the temporal aspects), they map the symbiotic relationship between humans and cobots into one of four classes: *coexistence, interaction, cooperation* or *collaboration*. Their classifications highlight the importance of investigating mental and emotional aspects in the use of collaborative robots and trust in the timing and environments where cobots and humans work together.

As the other way to classify the level of collaboration with robots, the four-level interaction readiness model was proposed by Christiernin [19]. The model classifies different types of human-robot collaboration (HRC) into distinct categories (0 - 3). The interaction readiness model focuses heavily on the task complexity as a parameter, in which more complex tasks require a higher level of collaboration. The model ranges from 'level 0: no collaboration,' which includes industrial robots and robots with high autonomy and low interaction necessities, to 'level 3: collaboration,' which is intended for robots designed for complex interactions such as service robots or drones. The author recognized the importance of categorizing and classifying various levels of collaboration and automation enabled by robots. Thus, a shared knowledge of possible ways to optimize human-robot interaction can be achieved. The importance of temporality is also mentioned. Whereas cobot and operator can work on the same object at level 1, this is always done in sequence (i.e., the robot goes into idle mode as soon as the operator takes over). A more simultaneous interaction process characterizes levels 2 and 3 where the cobot utilizes sensors to achieve awareness about the operator's location, thereby allowing them to work simultaneously.

As another example of the HRC classification model, Cesta et al. [10] proposed four unique scenarios of collaboration that can occur between a human operator and a robot in the same physical work cell. In contrast to the interaction readiness model [19], they considered two different parameters –the task and the temporal aspect– in their model. The four modes of HRC are Independent, Synchronous, Simultaneous, and Supportive, as visualized in [25]. The first mode (independent) represents the lowest form of collaboration. The task and workpiece of the human employees and cobots do not overlap, and therefore this process could be seen as two independent processes running side by side. The collaborative nature in these configurations stems from the close physical adjacency between human and cobot. The simultaneous mode is characterized by human and cobot working on different processes that are parts of a greater whole. Therefore, the operator and cobot collaborate towards a common goal. The sequential mode follows a pipeline process with the operator and cobot depending on each other. The second process (performed by the operator) requires the output of the first process (performed by the cobot). Supportive, as the fourth mode, requires the cobot and the operator to work on the same workpiece and process [25]. An example of this could be that the cobot rotates an object for the operator to fasten screws onto.

While the classification of different types of human-robot collaboration is based around a variety of different aspects — such as task-focused (e.g., [19]) or focusing on agent multiplicity (e.g., [87]), a common aspect seems to be the temporal. The temporal aspect (i.e., simultaneous or sequential) describes the relationship in timing of the interaction between human(s) and cobot(s) and plays a vital role in classification of human-cobot relationship (e.g., [10, 19, 86, 87]).

3 METHODOLOGY

Given the dearth of CSCW research on cobots in workplaces and on how such emerging technologies may shape a new form of collaboration with humans within workplaces, we set out to study work practices and experiences involving cobots.

Since our goal was to investigate cobots in the workplace while taking into consideration a variety of stakeholders, from cobot manufacturers to cobot users, we adapted our research design to accommodate for this focus. As potential informants, two of the leading cobot manufacturers in Denmark were chosen, as they were able to help us establish contact with companies who have implemented cobots. Furthermore, we analyzed 115 case studies (see Table 2 in Appendix A), and 14 semi-structured interviews with diverse representatives of four companies (see Table 1).

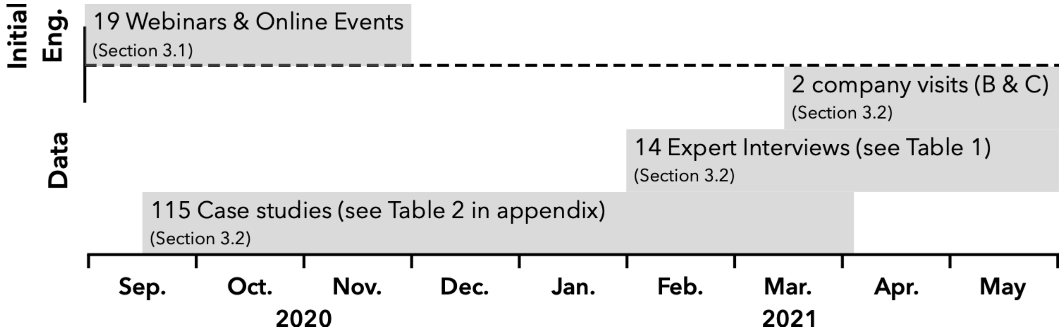

Fig. 1. Visualization of the four different data streams divided into Initial Engagement (see Section 3.1) and Data (see Section 3.2).

3.1 Initial Engagement: Attending Webinars and Online Events

The first author began by exploring cobot manufacturer companies' websites to learn more about their customers and industries, the technological advancement of cobots, and the companies' technological visions. This included attending webinars and online events (see Figure 1) hosted by the companies (e.g., Mobile Industrial Robots (MiR) and Universal Robots (UR)) and relevant organizations (e.g., Manufacturing Academy of Denmark (MADE)). The first author attended 19 webinars over three months, from September to December of 2020. The webinars, usually around an hour long, consisted of presentations by direct stakeholders (e.g., partners and customers of the cobot manufacturer companies) in which they often shared their experiences with cobots in production lines and lessons learned from them, or introductory presentations by the manufacturer companies on their cobots, outlining their major advantages over other industrial robots. The remainder of the webinars were typically question-and-answer sessions with the audience. Based on her observations, the audiences of the webinars were usually from companies considering integrating cobots in their operations. Participation in the webinars helped to acclimate her with common manufacturing terminology (e.g., high-mix low-volume, palletizing). Furthermore, we were able to establish contact to company B (see Table 1) through participation in the webinars.

3.2 Data Collection: Utilizing Case Studies, Expert Interviews, and Company Visits

We used three distinct data collection approaches, which form the basis for the findings presented in Section 4. These include the collection and analysis of case studies presented by two major cobot production companies (UR and MiR), 14 expert interviews with various stakeholders related to cobots, as well as observations from visits to two manufacturing companies (see Figure 1). We found the case studies on the websites to be useful resources in that they included testimonies of cobot users and described various perspectives on cobots. We used discourse analysis of case studies, which contained interviews, descriptions, and video footage from companies that have successfully implemented cobots into their daily operations, analyzing a total of 115 case studies, 86 from UR and 29 from MiR (see Table 2 in Appendix A). Case studies represented various sizes of companies (from 1-5 to more than 1000 employees) from 29 different countries, and included quotes from their employees in a variety of different positions (e.g., managers or production workers) and application areas (e.g., assembly, welding, or material handling).

The case studies, as marketing materials, primarily focused on the benefits of cobots and provided limited additional data on motivations for adopting cobots, challenges encountered in interacting with cobots, and so on. Importantly, most of the case studies represented one-sided perspectives of employees in managerial roles rather than those of production workers who work and interact daily side by side with cobots. In order to expand on the data collected from the case studies, the authors established a partnership with company A (see Table 1), one of the cobot manufacturing companies. Company A was able to help us establish contact with company C.

The first two authors visited two companies (B & C) in Denmark that had begun investing in cobots over the last three years. The companies B and C were vastly different in size (more than 2000 employees, and fewer than 50) and worked in different fields (actuator production and metal profile rolling and bending). We had the chance to get a first-hand view of cobots in the industry. At each company, we made observations of naturally occurring work [38] and interactions with the cobots. We also witnessed a demonstration of the work processes involving the cobots in the production cells [57, 58]. We took field notes and photos (see Figure 2 for examples) to be used along with other data in our analysis. During these visits, we conducted on-site interviews with five employees (P4, P5, P12, P13, P14). With the exception of P12, who was interviewed in Danish, all other interviews were conducted in English[2] (see P12 original statements in Appendix B). We used semi-structured interview protocols to explore the following topics: 1) the decision-making process of cobot adoption, 2) the trajectory to adapt to new work environments with cobots, 3) changes in task responsibilities prompted by cobots, 4) technological literacy, and 5) changes in interactions with other human workers and technologies.

In addition, the first author conducted remote interviews over a span of three months (Feb-May 2021) with nine employees in various positions (e.g., a senior researcher, an application engineer, and the head of global technical support) at cobot and end-effector manufacturers, companies A & D in Table 1. They talked about their experiences with cobots from marketing and sales, engineering, project management, and technical points of view. While all interviewees worked for Danish companies, not all were situated in Denmark (e.g., P1, P8, or P9). All individual semi-structured interviews lasted between 40 and 70 minutes, and audio recordings were afterward transcribed verbatim. All interviewees (P1-P14) and companies have been anonymized in this paper. As shown in Figure 1, the case studies and company visits were intertwined with semi-structured interviews.

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[2] According to the English proficiency index report [29], Denmark is ranked number two worldwide in terms of English proficiency as a secondary language.


(a) The cobot welding station in company C. The centrally placed cobot rotates 360°in order to place the welds around the round metal profiles.

(b) The pick-and-place cobot at company B. It picks the products from the transportation boxes and places them on the conveyor belt to be transported to the next step in the assembly line.

Fig. 2. Two examples of different cobots for different purposes. Figure 2a shows the welding cobot in company C, and Figure 2b demonstrates a cobot in company B using magnets in order to pick and place metal products.

ID	Name*	Position	Company*
P1	Ava	Country Manager (South America)	A
P2	Ben	Global Digital Marketing Manager in Denmark	A
P3	Caitlin	Senior UX Researcher in Denmark	A
P4	Dwight	Project Engineer in Denmark	B
P5	Emma	Project Manager in Denmark	C
P6	Frank	Sales Development Manager in Denmark	A
P7	Gabriella	Channel Development Manager in Denmark	A
P8	Harry	Area Sales Development Manager, Benelux	A
P9	Isabel	Technical support in East Europe	A
P10	James	Sales Support in Northern Europe & Benelux	A
P11	Kira	Application Engineer / Integration Coach in Western Europe	D
P12	Luke	Production Worker, Cutting	C
P13	Margot	Production Worker, Welding	C
P14	Noah	Chief Technical Officer (CTO) in Denmark	C

Table 1. Table illustrating the 14 interviewees representing four different companies, as well as their positions. *Name and Company are anonymized.

3.3 Data Analysis

In this paper, case studies and interview transcripts were primarily focused on and used for data analysis. For data analysis, we followed reflexive thematic analysis [6, 7] within a constructivist orientation [43, 53]. Besides Braun and Clarke [7], constructivist qualitative researchers [41] have emphasized that interpretive research needs to be reflexive; researchers should consider how their assumptions and positionings have been complexly involved in their research process and outcomes since knowledge is a result of social and cultural construction. Here we remark on our individual positionalities that we bring to this work, given our analytic approach [41]. Our research team was trained as HCI design researchers and computer scientists, with one of them focusing specifically on CSCW, in addition to her involvement in HCI and HRI research. We were concerned that, given our lack of expertise and knowledge of the manufacturing industry previous to this study, we would fail to notice politically and socially sensitive issues (e.g., worker-management conflict) during our research and so miss an opportunity to analyze them. Similarly, our educational backgrounds may influence our analysis, preventing us from properly empathizing with the operators and their blue-collar technical training in lieu of intellectual educations.

We also took an interpretivist approach by using inductive and iterative analysis without predetermined theories or frameworks, as a constructivist approach is firmly rooted in the interpretive tradition. The first author first read and re-read all texts, including video transcripts from the case studies and the interview transcripts, in order to familiarize herself with the entire data set. During initial coding, the first author independently coded and grouped relevant codes to generate candidate themes. To develop a more nuanced reading of the data, then the initial codes, themes, and analytic memos were circulated among the research team for theme review, discussion, and reclassification when necessary. The first author iterated the themes by going back to our transcripts and looking for specific data that supported these themes. Once discussed, themes were further refined during the research meetings. We share the themes in Section 4.

3.3.1 Power Dynamics in the Danish Workplace. While the majority of the interview data was from different non-production workers' points of view, we believe that the impact of this in terms of data validity is minimal, if present at all. The Scandinavian, and especially the Danish work culture, is known for its uniqueness in a flat hierarchical structure and focus on egalitarian structure [39, 55]. According to a recent World Economic Forum report[11, 30], Denmark has the highest 'willingness to delegate authority at work' among 140 countries, indicating flat hierarchies in the workplace. This lack of hierarchical-based system is to a large extent made possible due to the safety nets provided by the Danish welfare state, high amount of equality between employees, and the emphasis on unionization providing employees support and safety in the workplace [1]. Furthermore, the Danish work culture is unique in that it advocates a shift away from hierarchical management by emphasizing decentralized decision making and giving individual employees at all levels more autonomy over decisions that affect their jobs [8]. This emphasis on an egalitarian workplace contrasts with the concept of a nonperson [78], because all employees, from manager to production worker, have the opportunity to be heard and to voice their concerns and inputs equally. This delegating of responsibility in Denmark, thereby providing ownership to all involved employees, has been also nicely exemplified by Jonathan Grudin [33]: *"The Aarhus people start out with a problem situation defined by workers, and work beside them a long time in order to develop a new system that is 'owned' by the workers... This is very different from traditional systems development, as you can imagine, and you can't simply package a set of techniques to do the job [...]"*. Lastly, while many working cultures refer to the term 'power' to express standing in a hierarchy, this word is rarely used as it implies negative connotations; instead Danish workers typically refer to 'responsibilities' which is shared among all workers [39].

4 FINDINGS

The four major themes created from the data analysis are described in this section. These include (1) the introduction of cobots as a new technology and how companies use workers who were involved in the early stages of cobot adoption (later became ambassadors) to facilitate the cobot experiment, (2) work fragmentation leading to human workers focusing on peripheral tasks, (3) the lack of a fixed meaning of the term "collaboration," and (4) the significance of physical distance from a cobot workstation and how it affects collaborative space and work rhythms.

4.1 Countering Fear: Voluntary Operator Participation for Cobot Experiment

The first theme is related to the early stages of cobot implementation. This contains themes such as the motive for implementing this technology, the employee's anxiety that must be addressed before successful cobot installation, how a few workers became ambassadors among employees, and the positive consequences of this on cobot adoption.

4.1.1 Cobots as an Experiment. For most companies, collaborating with a robot itself was not a predominant motivation or goal but more like an experiment. For example, C7 was unsure about how human-robot interactions would be implemented into their workflow and whether this would be reasonable, taking their tasks and challenges into consideration. They ventured into installing cobots to explore potential solutions for increasing work productivity, addressing a labor shortage in the manufacturing industry, and preparing for future competition.

> *"Workers' organization changes depending on variations in the production volume, but every time it changed it led to problems like time overruns. We decided to see if using robots in locations where we were seeing time overruns could solve the problem. Furthermore, since we wanted to test how far we could take the collaboration between people and robots, we planned from the beginning to use [cobots from cobot manufacturer 1]."*

After installing the cobots, some were perplexed as to how to naturally incorporate them into their existing workplace and workflow. This integration required some strategic efforts and experimentation, such as pilot testing (e.g., C61, P4) or cobots introductory workshops for their employees - ranging from production managers to floor workers. A managing director (C61) described how involving their workers in the initial process of implementing cobots resulted in a smooth setup and introduction of the cobots: *"We asked if any of the employees were willing to be involved in the pilot project, and have thus been able to establish excellent cooperation between man and machine".*

4.1.2 Employees' Fear: We need the Human in the Mix. As almost all companies were well aware of the public perception of robotic automation replacing human jobs, the companies expected that their workers were likely to be intimidated by the introduction of cobots. A technical manager, for example, who introduced cobots at his workplace discovered such a barrier— workers' unjustified prejudice against a robot at work, which he couldn't readily overcome: *"...the biggest concern we had before the adoption of the [cobot from cobot manufacturer 1] robots was the wrong prejudice [that is] robots are here to take jobs away from people"* - C82.

The technical sales manager emphasized "togetherness" to materialize this definition of cobots: *"cobots need to work together with people in the same space...The cobots are realizing the concept that robots do not replace people but complement them by working together with people. We believe that robots cannot completely replace humans."* As the companies propagated what cobots were meant to be, cobots were expected to prove that human workers will remain in the workplace as "collaborators" with the cobots.

One of the challenges that companies face, particularly those that did not involve their workers in the process of adopting cobots, was allaying their workers' anxiety regarding the sudden introduction of cobots into the workplace. While C76 would retain their production team workforce with little change in tasks and positions, they felt the need to transmute any possible negative views toward cobots into positive ones: *"When the company [C76] initially bought the cobots, the production supervisor was trying to think of ways to get the production team excited about having a robot among them. He also needed a dedicated staff member on the line to be the robot technician who could oversee all robot operations."*

Little can be inferred from our data set of how the companies convinced their workers after they purchased the cobots. Yet, according to a managing director of (C61), the cobots' collaboration abilities have been used as a symbolic tool to assuage the workers' concerns about being replaced by cobots. He believes this is due to the fact that the collaboration part of cobots implies that human workers' roles and responsibilities are required for for smooth "collaboration" with a system. The managing director said: *"[s]ince we wanted to allay any fears our employees might have had, we put the emphasis on cooperation from the very beginning."*

4.1.3 Positive Words from the Few: Impact of Cobot Workers on Cobot Adoption. One strategy that companies have adopted is using their employees as positive messengers of cobots. Companies must turn their employees into "ambassadors" for the new technology in order to make the transition to cobots go smoothly (P8, P11, P4, P5, P14). The companies had asked their production staff if they were interested in learning about this new technology, and as a result, selected workers were exposed to cobots even before they were integrated into the company's workflow. Workers who took advantage of this chance were usually enthusiastic about new technology. Before the cobots were assembled on site, workers were able to obtain a better understanding of the cobots' capabilities and limitations, often gaining new insights. As a result, they developed a positive impression of the cobots and eventually became ambassadors for them. The involvement of workers in the entire adoption process is critical for the success of cobots, as without their support, the likelihood of cobot installation is greatly diminished. For example, P5 and P14 from company (C) proudly told us about their "ambassadors," employees who are used to working in traditional ways for most of their career until the cobots were implemented and now are near retirement. As P5 and P14 said, they were initially skeptical about the cobot, but they soon changed their minds. The workers see that the cobots could lessen their work burden, leading to them being able to postpone their retirements for a couple of years: *"In the staff, the old workers we have, they're over 60 years. They thought, and they said, 'Well, why should we have robots suddenly? Is it not good enough, what I am doing?'... today if we talk with the old guys they will not go in without the robot [then they say] 'No, no.' ... I think the one guy we have is 63. He told me, I think a half a year ago, 'I'll take two years more because I got the robot.' Yeah. That's fantastic"* - P5.

For the company, those older workers became an advocate for mediating the transition into a new work style with the cobots; particularly by showing that even for them, the technical barrier is low enough so that other workers too can operate the cobots:

> *"...if we are looking at a change in management perspective, they are really good ambassadors for the change in the production of it. You almost have this picture of an elder guy, of course they will not use modern technology. But they will, of course they will [use the cobots]. Just [we get] teach it to them [the workers] and they, when they learned it [a cobot], appreciated it and now they are fantastic ambassadors and they changed management."* - P14

P14 also stated how a couple of convinced workers could be so supportive and positively influence the rest of all workers' perspectives on the cobots. Although companies ultimately decided whether or not to adopt cobots and attempted to frame the cobots around the necessity of human workers' roles in operating them, the good words of a few workers had a long-lasting positive effect on the other workers' perspective on cobots.

> *"I think we had very good success with having them [workers] backing this decision up,...even if it's not the big things that they [workers] contribute with, but it's still just having them on my side of the table and being part of the project so that they can go out and scratch positive messages about this, and they can tell their colleagues about what's going on instead of just listening in a project room figuring out stuff that they talk about something going on somewhere,...So that's at least what we see just having one involved makes the complete department feel involved because they feel like one of our guys is with the project and they go out and tell the other colleagues on the shop floor what's going on ...Instead it comes from me as a project manager, it comes from one of them [workers] that's something completely different."* - P4

4.2 Cobots' Arrival at the Workplace: The Workers Focus on Peripheral Tasks

The second theme is related to the change in work tasks and the task fragmentation accompanying the introduction of cobots into industry. As companies begin to automate parts of their work processes, cobots are frequently integrated into these processes to perform tasks that were previously assigned to human workers, causing human workers to take on more peripheral tasks. When using the term "peripheral task," we are referring to multiple different types of tasks. These include domain-specific tasks, such as preparing the material on which the cobot would then weld, as well as cobot maintenance tasks, such as parameter tuning or resolving cobot errors.

4.2.1 Fragmentation of Work. Following the introduction of cobots, a previously coherent task completed by the human worker becomes fragmented, as described and illustrated in Section 4.2 and Figure 4. For example, traditional human tasks such as screwing components and picking-and-placing are now carried out by cobots.

Margot takes the two outer halves of a full circle and places them on a round, manually rotating table. Following this, the two inner halves of the circle are taken and placed inside the previous two rings, thereby forming a full circle profile with both inner and outer components. After placing the four metal profiles, Margot presses down the clamps, placed in 20-30 cm distances, around the table to keep them in place. She pays special attention to making sure that the distance between the metal parts that need to be welded together is as small as possible, as larger gaps will weaken the structural integrity of the weld. Following the clamping, to keep the parts in place, she equips her welding helmet and starts welding the pieces together at regular distances – the distance chosen depends on the inner radius of the metal ring. After each weld, she manually turns the rotatable table to bring the next point for welding into proximity. After the last weld is completed, she removes the now closed ring from the welding table and places it in the holding rack to start the process with the next round metal profile.

(a) *Vignette 1*

Following the clamping, to keep the parts in place, Margot retreats to the other side of the welding curtains, increasing the distance between cobot and her as well as providing eye protection similar to a welding helmet. Using the cobot control tablet, which is placed on the other side of the welding curtain roughly 3 meters from the cobot, she confirms that the parameters – such as waypoints or radius for welding head turns – are set up correctly. As this is the case, no changes are needed, and she presses the start button initiating the weld. Instead of rotating the table, the robot automatically re-positions its welding end effector to the next welding position. During the next one to one and a half minutes, depending on the radius of the profile being welded, the cobot automatically places the pre-defined welds in a 20-30 cm distance. During this time, Margot waits on the other side of the welding curtain. Following the last weld, the robot retracts into the center position of the table. Margot emerges from the other side of the welding curtain to remove the profile from the table and places it in the holding rack.

(b) *Vignette 2*

Fig. 3. Two vignettes illustrating the process of welding before and after the cobot introduction. The specific welding example is based on the observation and interview data of P13 in company C (Table 1).

> *"The robot has taken over the handling of lids for tobacco tins in the tobacco packing process, a task that was previously performed by hand. One or two people have been freed from this specific process thanks to the robotic arms and are now able to carry out other tasks at the factory."* - Line Manager at the C79

As the quote describes, with cobot implementations, it was inevitable that workers would take on "other tasks." Rather than specifying what kinds of collaborative tasks the human workers would now perform, instead it was stressed that human workers were now liberated from their old workload: *"...installing the [cobot from cobot manufacturer 1] cobot to tend resistive welders has freed up three operator functions"* - C78. The plant technician at C86 also expressed that the company moved out of its comfort zone with cobots and changed its manual processes which had been in place for 20 years. Human workers are now free of the old process: *"with the move towards automation, our manpower can be redeployed to other processes."*

To exemplify this, we present two vignettes illustrating a specific change of work routines the introduction of the cobot brought with it. These vignettes are based on a shift in the responsibilities and tasks of human workers as described and demonstrated by P13 during the interview and our company visit. The first vignette (see Figure 3a) describes the welding process of P13, Margot, prior

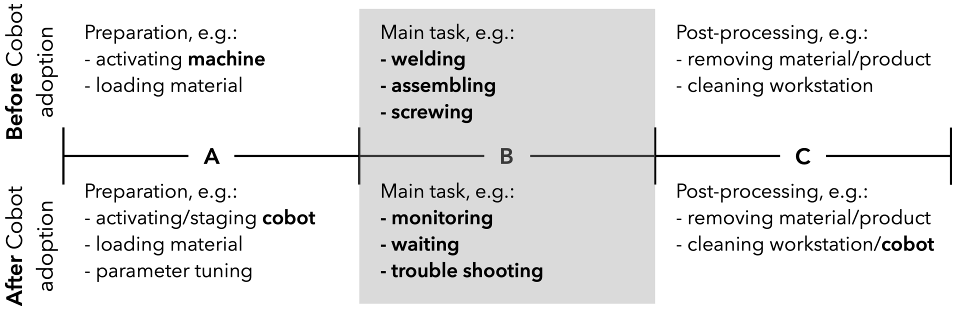

Fig. 4. Illustration of the change of production workers responsibilities before and after the adoption of the collaborative robot. Bold text and gray underlining highlights changes in human responsibility before and after the cobot adoption.

to the introduction of cobots. In contrast, the second vignette describes the same process following the cobot introduction. The setup for the cobot welding station presented in Vignette 2 is illustrated in Figure 2a. To condense Vignette 2, it will start following the preparation of the welding table, similar to Vignette 1.

As shown in Vignette 1, the entire process is completely manual, from placing the individual components, welding each seam, and manually turning the table, to unloading the table and preparing the next round metal profile. In addition, the welding itself requires a high level of manual labor expertise, as the welding seams require a high degree of precision to reduce internal air holes, identified through ultrasonic testing, leading to weakened structural integrity of the weld.

Prior to the introduction of cobots, the (A) preparation of the welding table, loading material and clamping it in place on the welding table, the (B) main activity– the welding, and the (C) unloading of the welding table, were perceived as one sequence of activities. Step A and C are considered peripheral tasks necessary to facilitate the main activity – the welding of the profiles. This high-expertise job has changed drastically following the introduction of cobots (see Figure 4). Vignette 2 describes the same process in the same company, following the introduction of the cobot.

We could observe that the contrast between vignettes 1 and 2, is not evenly distributed. While parts A and C are very similar in both the manual and the cobot-supported scenario, the main difference lies in part B. The entire task of Margot changes from being a welder to being a cobot supporter who focuses on peripheral tasks, such as preparation, parameter tuning, and post-processing after the cobot finished welding, resulting not only in a change of job title but also a job identity from welder to being a cobot supporter. However, it is worth noting that companies (e.g., C35, C63, C73, P5, P8) typically frame the shift of production workers' responsibilities to "higher value" or "more exciting" tasks as a result of the cobot.

Human workers now tend to do miscellaneous work surrounding the cobots, specifically assisting the cobots in taking over the human's tasks. We presented one example using vignettes in Figure 3. P12 provided another example of how the human worker's workflow changed: *"I just press the button and start the [plasma] burner and the robot, and then it cuts while I wait. Then I turn it off again and remove the cut pieces."* This fragmentation of work processes divided the responsibilities of production workers into three phases ((A) preparation, (B) main task, and (C) post-processing) before and after the cobot implementation, as shown in Figure 4.

> *"So let's say that there was ... a worker that was doing welding ... At the end of the day, this person, they might end up becoming validations cell operators, meaning they're not doing the bulk by themselves, but they are monitoring that everything is going okay, and*

> *they're doing small adjustments and checking that everything goes smoothly. So they become some sort of robot operator or robot supervisor."* - P9

We found that with the adoption of cobots, human workers tend to do the work that revolves around the cobots, specifically guiding, commanding, programming, and overseeing them. These work transitions tend to be positively accepted by the workers. Instead of performing manual welds, the operator now programs the cobot and inspects the product. An operator with no background in robotics said that *"It's a less monotonous process now and it's neat to watch all the systems interact with each other."* He told us that he had received a three-day training course and is now able to program the robot and oversee its operations (C78).

As the operator mentioned above, unlike manual and hand-skilled tasks, years of experience or proficiency are dispensable for programming and handling the cobots; for example, as the production line head at C48 said, *"Anyone can do [it] if they can use a smartphone"*. This allows for human workers to make a smoother and quicker transition to their new tasks. Another worker at (C36) elaborated on this point: *"We are not hiring expert staff to handle a high-tech robot. We are turning our staff into experts with their skills level on the increase...all workers can manage the robots and integrate them into their works, it's simple so other workers can easily do that like on/off. So it's collaboration."*

4.2.2 Overseeing Machines. By playing second fiddle to the cobots (e.g., "staging" the cobots), human workers are frequently viewed as a liability to the production line, required only when something goes wrong or when cobot tasks are thwarted or interrupted. A manager described how their production line can be more productive as less human engagement was needed: *"There's more consistency in the loading and unloading of the parts. It's taken away some of the human error"* - C35. In a similar line, Sam, production engineering supervisor at C76, mentioned that human workers would sometimes fail to identify screw insertions, as the holes in the housings were hard to see. The workers now on standby for malfunction alarms, as Sam continued to say: *"The [cobot from cobot manufacturer 1] hits all the screws all the time and if not, it will immediately notify us,"*

Monitoring (see Figure 4), in particular, was considered as one of the necessary "new tasks" for human workers regardless of the workers' status, including both temporary and permanent workers. For example, while workers monitor their cobots, supervisors monitor the workers who work alongside the cobots, resulting in a "monitoring cascade," as we found. A production manager (C51) said:

> *"Staff reaction to the [cobot from cobot manufacturer 1] – Victoria [name of the cobot] – has been extremely positive and they have upskilled as a result of cobot integration. New roles are being created for the team which are more focused on quality and process monitoring of material supply, compared to the role of a traditional assembly worker. We're so pleased to see the team's sense of pride in the new skills they've developed as a result of operating Victoria. Permanent staff have taken on the responsibility of mentoring temporary staff on how to work with Victoria."*

Human monitoring is often extended remotely. Despite that the human workers do not share their physical spaces with the cobots, it was considered a collaboration. For example, regardless of the time and place, a 3D printing company (C81) operator is inspecting and monitoring the cobots' performances even after hours: *"We can monitor the robot through our own software and access the status of any given printer to see whether it's printing or idle, which means we can deploy this in our factory and run it 24/7 without any human oversight"*.

4.3 Collaboration at Work: A Construct in Flux

As the adoption of cobots inevitably leads to work fragmentation and human workers took on new duties, we found that there is no fixed understanding of collaboration with robots in the current collaborative configurations – rather they have loose and ununified definitions of collaboration.

4.3.1 Collaboration Limited by the Technical Capability of Cobots. Our interviewees mentioned that the conventional meaning of collaboration is yet to be realized in the workplace involving cobots. Some interviewees (P4, P7, P9) showed their skepticism regarding the definition of collaboration in working with a cobot, saying *"Yeah, I think that we cannot actually define it, because this is a journey. I mean, we are not yet, let's say the ultimate human robot collaboration. And now we're getting them closer and closer every time. So basically, with robots being engaged, completely separated from a human operator, and then the collaboration is basically at least making them share the same workspace. So then they might not be directly interacting, but that is they are closer now. ...we are getting more and more in direction of more collaboration"* - P9. For P9, collaboration in the ideal sense is far from reality, but the meaning of collaboration will gradually evolve to reach the full definition of collaboration.

In a similar line, P1 expressed that the understanding of the term *collaboration* often is rather "theoretical", and this goes both ways for the [cobots from cobot manufacturer 1] themselves, as well as their customers. Often times, cobot producers and users do not put a lot of meaning into the term *collaboration*. The market defines a cobot as a robot without any physical fencing, especially since traditional robots have been confined physically to prevent potentially harming human employees. Customers sometimes misunderstand this notion by interpreting collaboration as the appearance of robots rather than their mechanical and functional conditions, she said:

> *"My understanding after working here [cobot manufacturing company] for four years and a half, I would say it [collaboration] is very theoretical. So you have different levels of collaboration and sharing the space, and I agree I used the concept and I like it very much. For the broad market, most people don't have that understanding. What they understand is a robot without fencing. That's what they understand. ... So when I think about collaboration, we are looking at robots installed without fencing. So for the local market, it's robots inside a cage or robots with no caging. That's it."*

Collaboration also was not the overwhelming concern among most of the customer companies, as P4 also noted that collaboration configuration tends to be rarely applied in the current workplaces: *"90% of the [cobot manufacturing] companies we started [working] with [to adopt cobots were from] Company A, having them doing some simple set ups because it was quite easy to get started with it. But most of the setups actually turned out to be a robot standing alone and handling parts, which could as well, have been an industrial robot."*

Given that collaboration has been understood in a broader way (e.g., sharing a workspace, giving human input to the operation of robots), P9 rather coined the term "collaborative operation" instead of collaborative robots: *"actually, it's not correct to speak about Collaborative Robot, but rather a collaborative operation. ... We are usually calling Collaborative Robots ones that they are, let's say, power- and force-limited robots. So basically, they cannot apply enough or too much power force to the environment. But there is not like a strict definition of what is a Collaborative Robot. ...We have robots, we have machines, and then we have different levels of collaborative operations."* As she pointed out, collaborative robots are distinguished by their technical capabilities that allow them to work alongside humans, such as the robot's limited physical impact.

4.3.2 Collaboration Formed by the Degree of Human Involvement. While the capabilities of cobots have shaped what collaboration means to our interviewees, the way that human workers are involved in this process with them did so too. For some of the interviewees, collaborative works are attributed to how much control humans have over a robot. For example, P11 pointed out that greater controllability highlighted the collaboration aspect of cobots among other technologies.

> *"I think the collaborative aspect is really important here because one of the major problems we have technology and stuff today, is that not enough collaborative... Your phone has a collaborative interface, but you cannot put your hands in the phone and you cannot say 'don't put it like that'. With the iPhone now, I can't even turn off the Bluetooth. I have to go into the settings and turn off the Bluetooth manually, it's completely crazy. And collaborative robots are easy-to-access technology, I would say. From a programming point of view, that's really great because the people that are using it have power over this."*

For both companies and their workers, collaborating with machines in manufacturing environments is nothing new. Our interviewee (P8), marketing manager of a cobot manufacturing company, explained why most of their customer companies cannot articulate the collaboration aspect of the cobots in many case studies. He said *"It is because it [collaboration] is so natural for them and because they are getting used to it already."* Then he went into depth about how the new workflow and tasks assigned to human employees are similar to what they used to be.

> *"Well, in the past somebody was getting the machine ready for production and then getting the parts there, open the door, get the part in, press the button to start, take it out, place it somewhere it does a quality check. And now somebody comes [to] get the machine ready to run but then prepares the robot, makes the right play there, puts all the pieces in the frame, gets the right program in, maybe adopts the program a little bit, press play. And once the checks for the first two, three, are they okay?...And once it's running fine, it can run for several hours without interruption."*

As he alluded, it is only the first and the last part of the work process in which the collaboration clearly emerges – the workers needed to set up the cobots in the beginning and do quality control checks at the end of the process. Regarding the middle of the work, the collaboration configuration ends and the cobots start running independently. The manager (P8) continued to say: *"that's why also they [our customer companies] don't talk about collaborativeness because you're not high-fiving with the robot at that moment. But the results which are bringing are high five...once they've made that decision [of buying the cobots], then it's just an ongoing project of installation and they forgot about what the collaborativeness at that point brings but they will remember it when they see the results."* He highlighted that collaboration components of the cobots did not come from collaborative actions or activities in the process but from the satisfactory outcomes of the collaboration. The collaboration aspects also came into view only when the production workers and managers consciously reflected on it. Cobots' technical specifications that enabled them to collaborate with humans did not offer the sense of collaboration.

As we've seen so far, our interviewees notice the collaborative character of their work with cobots in retrospect. Another marketing manager, P2 told us that the meaning of collaboration was something naturally established through the involvement of humans: *"We focus on what technology can bring. It can bring productivity. It can bring better labor conditions for workers. It can bring efficiency...But to be honest, we haven't focused on [the cobots' collaboration aspects]. If you're a CNC machine company, what should John be doing if he can't babysit the robots?"* As he noted, the cobots are inherently unable to work alone, and cobots require human inputs to accomplish any task.

Similarly, P4, a project manager, defined the cobots by emphasizing the labor of humans that is essential to the cobots' automatic operations: *"collaborative robots means that if there appears a failure, the operator can get in, solve the problem, get out in 20 seconds instead of using two minutes because he needs to open a safety zone and walk into the cell and restart it."* Collaboration happens around the cobots' failures where human workers can intervene and quickly take control over the operation.

4.4 Distance Matters: Collaborative Spaces and Rhythms

Another theme we identified is the importance of distance and how cobots at work reconfigure and extend workspaces. Particularly, because of the cobots' safety sensors, we find that cobots not only adjust the timing when human workers can intervene in a work process but also maintain "a collaborative distance" from humans, which creates "spatial rhythms." In other words, specific times when a human operator would be near to check on the machine or far away for their safety.

One thing that makes cobots different from traditional industrial robots is the cages that surround them to protect human workers from any danger posed by the robots' operations. The absence of cages is frequently promoted by cobots' manufacturing companies as an advantage, in that removing cages from around cobots saves money by substantially reducing workspace requirements and enables humans to work side by side with the cobots. The cobots' ability to collaborate is also often emphasized as a way in which companies can utilize their workspaces more productively. Thus, bringing cobots into the workplace requires restructuring the current space around the robots: *"[r]emoving the safety barrier allowed C46 to change the layout of the robotic centre and gain more space in the machine shop"* - C46.

While cobots do not require cages around them, keeping the distance can, in certain situations, improve the work environment. Company C, see Table 1, implemented cobots for the welding process, which was previously performed by a human worker. The addition of the cobot made the workplace safer by keeping workers away from toxic welding fumes. The benefit of this was expressed by e.g. P12 who stated:

> *"This is one of the huge advantages [of the cobot], when you weld yourself, even though there is a suction, you still are sitting in the welding smoke, whereas now you are standing in a separate cabin, then you start the cobot and then you walk out [while it welds] and not walk in until it is done. And the air suction that is on clears the smoke before you enter."*

Besides helping companies be more financially efficient in physical workspaces through cobots, collaboration with cobots is not limited to just space. By removing the cages that surround the robots, both the robots and humans gain more mobility. Collaboration takes the form of being "physically close and accessible to robots," possibly in any space. For example, one company (C66) has used the [cobots] for various "daring" projects such as use on construction sites and vector artworks. The research engineers who brought the [cobots] outside their conventional workplace into a park to draw portraits said, *"[t]aking a robot to this unknown place was an interesting challenge... We could bring it [the cobot] out in a Pelican case. Had we used one of our traditional robots, it would have required a forklift and a safety cage so that would never have worked."* Another employee described the closer proximity to the cobots: *"I could literally connect the robot to my laptop, work next to it, and quickly iterate through our experiments."*

However, due to remaining safety issues, some companies still divide the spaces between humans and cobots. For example, the robots have "area scanners" activated *"when employees cross the yellow and black striped lines on the floor outlining the boundaries of the work envelope."* For the cobots, sharing their workspace with human workers was seen as an interruption in their work: *"Once the area scanners are activated, they send a signal to the robot to slow down its operating speed. When the employees leave the work envelope, the cobot picks up its usual speed"* - C76.

C13 chose to implement lightweight plexiglass guards and curtains to separate human workers and cobots in the interest of "collaborative speed'," where human workers can easily access the robot. We find that collaboration must be in tune with the rhythm of human workers' activity and movements: *"if a worker opens a door or reaches through an active area, the robots immediately drop into a safe collaborative speed. Once the worker shuts the door or moves out of the light curtain, the robots resume their maximum speed."*

The use of distance as a safety mechanism makes collaboration possible with cobots. When we asked why he chose collaborative robots rather than high-speed traditional industrial robots, he described collaboration as a separate pursuit from productivity:

> *"You can go as fast as you need to and make sure you can keep up production rates, but you can also be collaborative if that makes more sense. It's the best of both worlds."* - C13

With the robots' active safety mechanisms, collaboration is achieved in a way that human workers do not have close access to robots, but maintain distance without physical contact. We see this form of collaboration as "semi-remote collaborations." For example, the team at C20 is very satisfied with the security measures associated with collaborative robots. They describe how their cobots are sensitive to anything within range: *"the operator can enter the cell at any time and the robot stops instantly due to additional sensors that stop when the operator gets close to the robot."* In this case, collaboration, such as humans' supervising and directing robots, is often achieved without direct contact with the robot. Collaboration doesn't demand human physical labor, only constant human attention and instructions.

5 DISCUSSION

We just presented four overarching themes from our data, as shown in Section 4. The first theme is the importance of involving not only management but also production workers (i.e. prospective cobot operators) in the initial process of introducing cobots prior to their implementation. As a result, operators can become advocates, resulting in a more positive perception of the cobots and less fear of it. Second, bringing cobots into the workplace has a substantial impact on current work routines. While it eliminates some duties (such as welding or pick-and-place), it also provides new tasks that revolve around the cobots (e.g., monitoring or staging the robot). The cobots not only disrupt existing work practices (e.g., fragmenting work into subtasks and peripheral tasks) but also alters job titles and essential responsibilities (e.g., from welder to robot operator). Furthermore, while the name "cobots" indicates that the robots work together, true hands-on collaboration is rarely the case. Instead of collaborative robots, the process of working with this technology is more akin to a "collaborative operation," which is defined by the absence of physical barriers, to borrow P9's term. Finally, we described our findings on the significance of distance and space sharing with the robot. This has two advantages: it improves the working environment and gives the manufacturing line more flexibility.

Below, we discuss the implications of fragmented and peripheral human labor to the larger question of human workers' upskilling and deskilling. And then we introduce the concept of bounded collaboration, its characteristics, and potential contributions to CSCW. Finally, we provide design implications for researching industrial workplaces with cobots.

5.1 Fragmentation of Work leads to Loss of Job Identity

As we have presented throughout Section 4, the introduction of cobots in the industrial workplace can lead to unintended consequences. In this section, we want to elaborate on one of these, namely the fragmentation of work (see Section 4.2) and the following related loss of job identity.

5.1.1 Rebranding Jobs around Cobots. As presented in section 4.2.1, the change of work nature due to the fragmentation is presented as a change towards "high value" or "more exciting" tasks. Just as Farshchian [28] inquired about each collaborating party's values, it is possible to inquire about whom such high value is for. It could here be argued that this fragmentation of one coherent human task to three smaller tasks (see Figure 4), of which only two are the humans' responsibility, provides value to both the company and the worker. While the company increases productivity manifold, the human worker has frequent shorter breaks in their workday, leading to a potentially less stressful day. On the other hand, it could be argued that the entire job position changes overnight, leaving the human worker in a position distant from the actual task they were trained and hired for (e.g., the welding). Margot, in the example presented in the vignettes in Figure 3, used to be a trained welder prior to the cobot introduction; this is replaced by a new role for the robot like "support staff" overnight. This change from e.g., 'welder' to 'robot supporter' is additionally enforced by the spatial distancing from the main task (B), as illustrated in Vignette 2. Here Margot steps away from the robot to monitor it, behind the welding curtain, and thereby distances herself from the main tasks, potentially decreasing the sense of situational awareness [36].

5.1.2 Broadening our Views on Skills. While the production workers described their responsibilities during part B as rather simple (see Figure 4), sometimes as simple as just 'waiting for the robot to finish' (P12 in Section 4.2), the production workers still liked this new work and took pride (e.g., see quote by C51 in Section 4.2.2) in the new responsibilities. The new, if unofficial, title of "robot operator" (e.g., P2, P8, or P11) or "robot technician" (e.g., C76) seemed to provide intangible value to the production workers, signaling an upgrade to responsibilities and capabilities. A recent study by Beane [4] demonstrated a similar effect in the setting of a hospital. While the introduction of robots was meant as an investment to increase instrumental value, only signaling value was achieved, as the hospital seemed to be a "cutting-edge" hospital investing in the newest technology. While it is questionable if workers were upskilled in competencies through the implementation of cobots and the change of responsibilities that resulted, the implementation improved employee satisfaction [4]. Less attention is placed on the main task as staging and sustaining the cobot operation has become more of a work routine (B as illustrated in Figure 4). This can in turn can lead to a deskilling in (individuals') competencies [36, 40, 47].

Simultaneously, as the nature of human tasks has changed to become more peripheral and fragmented, the required skills now rely more on abilities to communicate with other workers and to coordinate the work (e.g., understanding the entire work processes to be able to oversee them) than on individual knowledge or proficiency of the main tasks. Fellow operators, for example, assist one another in gaining competency in operating and engaging with cobots by providing training. P11 stated that *"one operator that learned his/her way around the robot will then create training material for each colleague, his/her colleagues in the factory. And then train new colleagues to this technology"*. Despite the fact that skills were previously regarded as individual qualities, here skills are transferred to collective competencies that a group of workers share; skills are now looked of as group properties. We call attention to thinking beyond the traditional division between upskilling and deskilling viewpoints on skills. We should consider skills in a broader sense than individual ability to execute specific actions in order to prepare workers for workplaces that are changing due to new technology. When designing a cobot-assisted workplace, for example, we would need to prioritize collective competences such as group coordination to develop and maintain informal group ties and communication for problem solving or creating tacit knowledge over individual skills [32].

Aside from the changing nature of human jobs, our study also revealed how collaboration was obfuscated in the presence of cobots. With fragmented and peripheral tasks assigned to human workers, our stakeholders and workers often struggled to articulate particular workers' main activities. If our design aim is worker empowerment, we would need to make it easy for managers and employees to grasp how cobots have influenced their new duties and roles. Furthermore, our design orientation would need to support workers by providing them with ample time to experiment with new technologies so that they can gain better knowledge of their changing work practices [26, 68].

5.2 Bounded Collaboration with Cobots

Twenty-seven years ago, Heath et al. [37] already addressed that collaboration has been rarely defined in the CSCW community, as the common understanding of the term "collaboration" is often taken for granted. As we presented in this paper (see Section 4.3), collaboration in the workplace is not a static construct but rather a term that shifts its meaning depending on different contexts, e.g., where the cobots intervened, workers and managers' impressions on cobots, or the kinds of task responsibility given to cobots. For example, collaboration aspects of the cobots were described as things "on a journey." The interviewees also told us that collaboration is inherent to the nature of "work," so collaboration is too natural to be recognized or be articulated from their experiences of working with cobots.

Despite the ununified and context-dependent meanings of collaboration, we have seen few studies of collaborative technologies that articulate what collaboration means in their study contexts and how collaboration configuration may be restructured over time or differently perceived by other stakeholders. We argue that the meaning of collaboration should be questioned and revised in light of the study contexts. As we showed in our findings, collaboration aspects of the cobots were not the pressing demands or the most interesting parts for the employees who directly interact with the cobots everyday at work. If we want to realize collaboration activities through the technologies we design, we must understand where the potential users expect to gain benefits of collaboration. We have learned much from the early CSCW works on conceptualizing "users" [15, 91]. Similar to how reconceptualizing the concept of users (e.g., from individualist cognitive formulations of the user [59] to users in more complex social contexts) has allowed us not only to reestablish positions of human subjects in HCI research but also to reflect the current research methodologies and design evaluations (e.g., from laboratory experiments to ethnographic studies), we also call for paying more attention to the concept of "collaboration." As the re-conceptualized users did, re-conceptualizing collaboration may dramatically affect how we design and implement emerging collaborative technologies.

Collaboration is a major phenomenon that the CSCW community has long been interested in, and this interest distinguishes CSCW from other fields [69]. Given that, understanding the nature of collaboration is inevitable if we want to better support people's usage of collaborative technologies around their work practices. Dissecting and defining collaboration also could help us understand other forms of collaborative activities more clearly. For example, many scholars have questioned and explored what cooperative work means in CSCW, allowing us to establish the characteristics of cooperative work and crystallize them into the concept of cooperative work within CSCW. [3] Sørgaard [77] characterizes cooperative work as non-hierarchical and somewhat autonomous work. Other scholars have questioned the term 'cooperative' since it implies compliance and shared views, which may not always apply in daily work contexts. For this reason, 'collective work' was proposed as a more general and neutral alternative term. Along similar lines, 'collaboration' and 'cooperation' have been deemed to have overly positive connotations, with Kling [44] proposing the term 'coordination' instead. As these close examinations of cooperative work provide rich discussions and a basis to define important concepts in CSCW they inspire, for example, nuanced

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[3] please note that other fields have also engaged in discussions on defining cooperative work, considering, for example, 'cooperation' as independently working on subtasks toward a shared goal and 'collaboration' as working on shared tasks toward a shared goal.

distinctions among terms such as 'collaborative work', 'collective work', and 'group work'. We equally hope to make a contribution by unraveling how collaboration has been uniquely molded by diverse stakeholders of cobots.

In addition to the disunified meaning of collaboration in our study, we've shown that collaboration was not fully performed through the cobots. Specifically, we illustrated the limited work arrangements and advancement of technologies that limit collaboration between human workers and cobots (as shown in Section 4.3). Overall, collaboration was not deemed to be either *fully perceived* or *achieved.* As Herbert Simon coined the famous concept of bounded rationality– that is, rationality is delimited by available information in a constrained environment, we refer to this unfledged collaboration configuration as *bounded collaboration.*

5.2.1 Defining Bounded Collaboration. While cobots' manufacturers and their direct stakeholders found some collaboration capacities of cobots (e.g., cobots are safe enough to work side by side with humans), the collaboration is either minimally visible or hardly articulated during the actual use of cobots with changing human tasks and responsibilities. We refer to this form of collaboration as *"bounded collaboration,"* meaning that the anticipated collaboration is only partially manifested within a collaborative technology. Bounded collaboration can take one of four forms:

- utilizing collaboration as a symbolic meaning rather than an instrumental value (e.g., signaling its technological advance via its collaboration capacities, or collaboration as a reductive reason to attribute a satisfactory outcome to the work),
- emerging collaboration efforts obscured by being confused with the nature of the current work process (e.g., collaboration has been effortless in the manufacturing process),
- sporadic collaboration mainly on non-primary tasks (e.g., human intervention in cobots' work to fix their errors), and
- collaboration that is spatially and temporally constrained (e.g., humans matching cobots' working speeds while remaining conscious of the importance of maintaining a safe distance).

To describe these kind of interactions, we coined the term *bounded collaboration*, a form of unarticulated collaboration facilitated by current collaborative technologies such as cobots.

5.2.2 Characteristics of Bounded Collaboration. Michalos et al. [52] envisioned four different kinds of human-robot collaboration by classifying possible collaboration along two dimensions – how tasks are performed (whether human and robot tasks are separate or shared) and where robots and humans perform their tasks (whether they share the same workspace or have their own work stations). The matrix of these four possible collaborations is that humans and robots have: 1) shared tasks and workspaces, 2) separate tasks and shared workspaces (when humans are active in turn-taking), 3) separate tasks and shared workspaces (when robots are active in turn-taking), and 4) shared tasks and separate workspaces. Regarding separate tasks (a collaboration of 2 and 3), tasks require non-concurrent action by humans and robots. In this matrix of four types of collaboration, bounded collaboration would correspond with the collaboration of types 2 and 3, where robots and humans are co-located and assigned different tasks. This could be interpreted as bounded collaboration, given that robots and humans seem to collaborate while nominally working at a shared workstation, but it's hard to articulate how their work comprises collaboration.

In the other model of human-robot collaboration, Krüger et al. [46] proposed three levels of human-machine collaboration based on distribution of task responsibilities: non-adaptive tool use, adaptive tool use, and cooperative assistance. Non-adaptive tool use is interaction where humans have full responsibility in their interaction (e.g., wielding a hammer). Adaptive tool use is where a tool is able to adapt to environmental variations (e.g., driving with cruise control). Cooperative assistance is where humans and robots adapt to each other's actions and states to achieve a shared goal. Krüger et al. [46] see these three levels in a spectrum from low to high levels of human-machine collaboration. Based on this model, the bounded collaboration in our study would be classified mostly as adaptive tool use, given that while cobots have advanced sensors to detect human workers, human workers should adapt to the paces and spaces of working cobots. Following this, not all task responsibilities reside with human workers, and more importantly, new tasks that humans take on are often not conspicuous (e.g., often when a cruise is operated automatically, the navigator's monitoring actions are not always noticeable). This aspect of collaboration is bounded collaboration.

5.2.3 CSCW Contribution of Bounded Collaboration as a New Concept. We just defined bounded collaboration and expounded its characteristics by drawing upon two models of human-robot collaboration. Systematically abstracting certain phenomena is often vital to developing a fundamental understanding of a given phenomenon (e.g., [13, 16, 17]), in this case collaborative work practices [69]. Conceptualizing certain statuses of collaboration that we identified in our study of collaborative robots allowed us to see different forms of collaboration manifested in the workplace. By recognizing the rich nuances and differences among various forms of collaboration, we can find ways to embrace and support them accordingly. As Kling [44] pointed out, the concepts of collaboration and cooperation tend to connote a highly positive status implying stable and undisrupted conditions where the division of work and responsibilities are clearly defined and assigned. This may obscure or overlook potential challenges posed by the design of collaborative technologies. The concept of bounded collaboration instead suggests other possibilities generated by collaboration. Bounded collaboration offers an alternative way of understanding collaboration arrangements, such as an instance in which an expected collaboration configuration is poorly articulated or a collaborative technology constrains work space and time. We need concepts that acknowledge and augment all possible collaboration configurations. This, we believe, would broaden and clarify the scope of CSCW research.

5.3 Implications for Researching the Future of Work with Robots

5.3.1 Leveraging Social Dynamics in the Design of Workplace with Cobots. The investment decision towards the adoption of new technologies is typically made on a managerial level, related to return of investment. While prior studies [21, 22, 97] have suggested that early active involvement of production workers in the decision-making process is conducive to embracing new technology, they haven't specified how production workers might participate in the process. In this paper, we presented the practices of current manufacturing industry companies when they considered adopting new technologies, i.e., cobots (see Section 4.1). The companies were fully aware that not only would successful cobot integration be impossible without the involvement of production workers prior to the implementation of the cobots, but also that their involvement would not be the end. The companies discovered that manufacturing workers who were involved in the early stages of experimenting with cobots may function as 'ambassadors' for the robots. As our studies revealed, such workers shared the word about the positives of using cobots among their coworkers. They are the workers who found the benefits that cobots may provide for them while participating in company decision making.

Given that a few supportive employees influenced the collective workers' attitudes toward cobots, this exemplifies one manner in which a company can naturally accept new technologies. Similarly, Grudin and Palen [35] described how social dynamics such as peer pressure can lead to groupware adoption and success; in the case of Microsoft SCHEDULE+, non-users were subjected to peer pressure when they received application scheduling messages via regular email from their coworkers, and they ended up adopting it without any managerial mandate. We may need to leverage social interaction and dynamics among targeted users in our design of supporting organizations or groups that plan to incorporate new technologies into their work, by closely examining who created a positive image of the technology and how they delivered it to others, given how peer pressure can influence a group's views on a new technology.

Several work studies of CSCW have shown the importance of formal direct communication between peers (e.g., [9, 45]). At the same time, the studies proposed having more formalized means to coordinate such informal communications among workers due to the ephemeral nature of information and the transitional costs. Carstensen and Sørensen [9] called the ideal information flow "from the social to the systemic"–that is, from informal communication among the end-users to a formal meeting with decision makers in the company. Our findings suggest the opposite: there were more positive effects when the formalized information (e.g., the decision to adapt cobots and the subsequent process) was delivered through informal routes (e.g., small talks among production workers). Thus, one specific way of taking advantage of workers' involvement in adopting new technologies could be following the strategy "from the systemic to the social."

5.3.2 Being Difficult to Access the Industrial Context. With this study, we want to highlight some open-ended questions related to challenges prevalent when investigating the industrial context. While the CSCW community has had an increased focus on studies involving office workers [60, 65] and medical workers [12, 27, 56], it has been a new challenge to capture practices and experiences of work within the industrial setting. Additionally, our community lacks desirable methods for studying production workers and their work environments [18, 47].

Due to the extremely limited access to production lines and frequently increased security measures, gaining access to these settings posed a unique challenge for our project. After this first hurdle, i.e., the contact establishment with a company that allows access to its perimeter, was solved, we were able to visit companies B and C, listed in Table 1. Company managers mediated all interviews (both formal and informal) with the workers we talked with. While the majority of the workers' responses were positive, it's possible that they censored themselves and modified their viewpoints in order to conform to the company's policy/stance on the newly acquired technology. However, in light of Danish work culture, we are certain that this is not the case in our research (see Section 3.3.1).

Among the two just-discussed potential challenges that researchers could face while conducting fieldwork in manufacturing workplaces —access to manufacturing companies' sites and genuine perspectives of workers and stakeholders—are methodological challenges that we have yet to resolve: What tacit knowledge do the workers possess and what methods can be used to access these? How can researchers maintain long-term relationships with field sites when one considers the organizational and technological changes over time [14, 18]?

5.3.3 Limitations and Future Work. In this study, we made an attempt to include many different data channels that can represent perspectives of diverse stakeholders toward accepting and using the cobots in manufacturing production lines. The case studies (see Table 2 in Appendix A) that we investigated come from a global background, representing 29 different countries. It might be argued that the case studies in our data sets are not impartial because they operate as potential marketing materials by being published on the cobot manufacturers' websites and therefore portraying cobots in a potentially good light. We recognized that this could be the case, which is why we chose to supplement our data with additional sources such as interviews and observations collected during the visits to two different companies that have implemented cobots.

The four companies of which we examined and interviewed their employees were all Danish companies, although not all interviewees were situated in Denmark (e.g., P1, P8, or P9). Eight of the interviewees were from a cobot manufacturer company and the rest of them (six) from companies using cobots. Their positions were from the CTO to production floor workers. Although our data sets consisted of heterogeneous groups, we could not find any noticeable culture difference in their perspectives around cobots, depending on the participants' different roles and positions or the geographical area that they are based in. This could be due to the fact that all participants work for Danish companies and hence reflect the Danish work culture. As our research focus was neither on power dynamics between different positions nor on cultural differences, a different approach or analysis might be needed in order to identify comparable perspectives between the groups. A follow-up study, extending outside the Scandinavian region and utilizing additional data collection and analysis methodologies, would be necessary to examine tensions between employees in different positions within organizations (e.g., managers vs. production workers) or with disparate interests (e.g., employees in cobot manufacturing companies vs. in companies using cobots). While we acknowledge that the majority of the interview data was from different non-production workers' points of view, we believe that the impact this has, in terms of data validity, is minimal, due to the strong emphasis on egalitarian work culture, in which every worker has visibility [80]. In Section 3.3.1, we addressed this in detail. The investigation of to what extend this is generalizable requires further studies with work cultures in different geographical regions.

Lastly, while we managed to have a diverse sample in terms of job position, we did not manage to establish contact with high gender diversity, as only two of the interviewees were female (names in Table 1 are anonymized). At the same time, this also naturally shows the gender diversity of the manufacturing industry where women are still significantly under-represented.

6 CONCLUSION

In this paper, we have investigated the impact of collaborative robots on workplaces and human work and how "collaboration" is understood and implemented in industrial workplaces. We collected empirical data from a variety of different stakeholders and data collection approaches. By investigating the impact of cobot implementation along the entire temporal spectrum, from pre-introduction to completed implementation, we identify a variety of key findings: the early inclusion of supportive production workers in the cobot adoption process; the loss of job identity due to work fragmentation caused by the cobots implementation; the lack of unified meaning behind the word "collaboration"; and the collaborative workspace's impact on human workers and the change in work rhythms between humans and cobots. Furthermore, our research demonstrates how, during the use of cobots with shifting human jobs and responsibilities, collaboration with cobots is either barely observable or poorly expressed. We define this form of collaboration as bounded collaboration. We argue that understanding the nature of collaboration is necessary in order to better support people's use of collaborative technologies in their work practices. Defining and articulating collaboration could aid us in further understanding different types of collaborative practices that occur in the workplace, as well as finding strategies to embrace them in our design. We need concepts that recognize and describe all conceivable collaboration arrangements, which would help broaden and clarify the scope of CSCW research.

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APPENDIX

A CASES

Case ID	Industry	Country	Employees
C1	Scientific and Research	Germany	300
C2	Aerospace and defense	USA	170
C3	Metal and machining	France	37
C4	Metal and Machining	Netherlands	35
C5	Metal and machining	USA	25
C6	Metal and Machining	Germany	100–500
C7	Automotive and Subcontractors	Japan	3,200
C8	Automotive and Subcontractors	Germany	400
C9	Plastic and Polymers	Australia	50
C10	Furniture and Equipment	Canada	120
C11	Electronics and Technology	Germany	820
C12	Plastic and Polymers	New Zealand	Nov/50
C13	Pharma and Chemistry	USA	175
C14	Electronics and Technology	USA	12
C15	Electronics and Technology	Germany	1000
C16	Food and Agriculture	Japan	1235
C17	Electronics and Technology	Austria	1000
C18	Automotive and Subcontractors	Spain	201–500
C19	Metal and Machining	USA	40
C20	Automotive and Subcontractors	Spain	600
C21	Electronics and Technology	Germany	23
C22	Food and agriculture	Norway	100
C23	Plastic and Polymers	USA	135
C24	Pharma and Chemestry	Italy	30
C25	Plastics and Polymers	United Kingdom	50
C26	Metal and Machining	Austria	25–50
C27	Automotive	USA	700
C28	Automotive	Japan	343
C29	Food and Agriculture	Sweden	1,500
C30	Plastic and Polymers	Switzerland	6
C31	Scientific and Research	India	700
C32	Automotive and Subcontractors	USA	190
C33	Furniture and Equipment	USA	80
C34	Electronics and Technology	Canada	250
C35	Metal and Machining	USA	48
C36	Pharma and Chemistry	Spain	600
C37	Metal and Machining	Poland	36
C38	Automotive and subcontractors	Japan	4500
C39	Plastic and Polymers	Denmark	31
C40	Automotive and Subcontractors	USA	>50
C41	Food and agriculture	Italy	85
C42	Scientific and Research	USA	300
C43	Scientific and Research	Czech Republic	70

C44	Metal and Machining	Sweden	25
C45	Food and agriculture	Sweden	30
C46	Metal and Machining	Czech Republic	50
C47	Metal and Machining	New Zealand	50
C48	Electronics and Technology	USA	124
C49	Metal and Machining	USA	230
C50	Electronics and Technology	USA	300
C51	Furniture and Equipment	New Zealand	250
C52	Metal and Machining	Singapore	53
C53	LEAX Group	Sweden	1,100
C54	Electronics and Technology	USA	160
C55	Automotive and subcontractors	Germany	132,000
C56	Metal and Machining	USA	40
C57	Scientific and Research	Czech Republic	54
C58	Metal and Machining	Vietnam	400
C59	Pharma and chemistry	USA	3,500
C60	Automotive	India	80
C61	Electronics and Technology	Germany	350
C62	Pharma and Chemistry	Denmark	1,633
C63	Automotive and Subcontractors	France	15
C64	Metal and Machining	Netherlands	50
C65	Plastic and Polymers	United Kingdom	10
C66	Electronics and Technology	USA	10,000
C67	Metal and Machining	Finland	Oct/15
C68	Furniture and Equipment	USA	72
C69	Electronics and Technology	Denmark	15
C70	Furniture and Equipment	Denmark	45
C71	Scientific and Research	Poland	4151
C72	Metal and machining	USA	16
C73	Furniture and equipment	Switzerland	11,000
C74	Automotive	Germany	1000
C75	Electronics and Technology	Thailand	1500
C76	Electronics and Technology	USA	140
C77	F&B, home care, personal care, oils	Singapore	500
C78	Automotive and Subcontractors	USA	65
C79	Food and Agriculture	Denmark	130
C80	Metal and Machining	India	10
C81	Plastic and Polymers	USA	22
C82	Food and Beverage	Korea	13
C83	Plastic and Polymers	Denmark	3500
C84	Plastic and Polymers	New Zealand	100
C85	Furniture and Equipment	China	6,000
C86	Electronics and Technology	Indonesia	2,900
C87	Transport of materials/products	Denmark	200
C88	Transport of materials/products	Poland	>300
C89	Transport of materials/products	China	NA
C90	Transport of materials/products	Denmark	NA
C91	Transport of materials/products	China	NA

C92	Transport of materials/products	Poland	92000
C93	Transport of materials/products	Finland	800
C94	Transport of materials/products	China	NA
C95	Transport of materials/products	UK	NA
C96	Transport of materials/products	Spain	NA
C97	Transport of materials/products	Mexico	NA
C98	Transport of materials/products	North America	NA
C99	Transport of materials/products	Slovakia	700
C100	Transport of materials/products	Denmark	NA
C101	Transport of materials/products	Germany	1200
C102	Transport of materials/products	Denmark	NA
C103	Transport of materials/products	USA	NA
C104	Transport of materials/products	Spain	NA
C105	Transport of materials/products	USA	NA
C106	Transport of materials/products	UK	NA
C107	Transport of materials/products	Spain	40–50
C108	Transport of materials/products	Denmark	NA
C109	Transport of materials/products	Austria	NA
C110	Transport of materials/products	Italy	NA
C111	Transport of materials/products	USA	NA
C112	Transport of materials/products	Denmark	NA
C113	Transport of materials/products	Denmark	NA
C114	Transport of materials/products	Denmark	NA
C115	Transport of materials/products	Denmark	145

Table 2. Documentation of the 115 case studies including unique identifier, application, country as well as size. The data is presented as provided cobot manufacturer 1 (C1 – C86) and cobot manufacturer 2 (C87 – C115).

B ORIGINAL QUOTES

This section includes the original quotes in the Danish language of Interviewee P12 used throughout the paper. All other interviews were conducted in English.

Original transcript for the P12 quote on page 14:

> *"Jeg trykker knappen og så tænder den [skære]brænderen, så trykker jeg igen og så skærer den mens jeg bare står og venter. Så skal jeg slukke den igen og løfte delene ud."*

Translation:

> *"I just press the button and start the [plasma] burner and the robot, and then it cuts while I wait. Then I turn it off and remove the cut pieces.".*

Original transcript for the P12 quote on page 18:

> *"Det har jo nogle kæmpe fordelle [ved cobotten], at du ikke sidder og skal svejse, selv om du har udsugning på sidder du jo i det røg, hvor vi nu står inde i kabinen og så starter du cobotten og kan gå ud [mens den svejser] og ikke gå derind før den er færdig. Og så er der udsugning på og så er det røg væk når du kommer derind."*

Translation:

> *"This is one of the huge advantages [of the cobot], when you weld yourself, even though there is a suction, you still are sitting in the welding smoke, whereas now you are standing in a separate cabin, then you start the cobot and then you walk out [while it welds] and not walk in until it is done. And the air suction that is on clears the smoke before you enter."*

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