Facilitating Robots at Home

A Framework for Understanding Robot Facilitation

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***Abstract*—One of the primary characteristics of robots is the ability to move autonomously in the same space as humans. In what ways does movement influence the interaction between humans and robot? In this paper, we examine how work is changed by the deployment of service robots. Through a multiple case study, the phenomenon is investigated, both in an industrial and domestic context. Through analyzing our data, we propose a framework for understanding the change of tasks named the Robot Facilitation Framework.**

Keywords-robots; facilitating; tasks; work; domestic; human-robot interaction

I. INTRODUCTION

Robots have been used in factories, offices, and hospitals for several decades. They have been cleaning floors, transporting materials, keeping watch, and operating in dangerous environments to reduce general labor and costs [1][2]. The typical aim of introducing robots into workplaces is to increase productivity by automating work, which will decrease costs by reducing the amount of manual work [3]. But often the result is not so much a *reduction* of manual work as a *redistribution* of manual work. As robots are introduced into work environments, the way work is performed in that environment *changes*. For instance, Argote et al. [1] reported that the work of the operators in their study shifted from primarily manual lifting activities to cognitive monitoring activities. Recently, the addition of robots in Amazon warehouses changed the workers' days from being centered around lifting to keeping an eye on the robots [4].

Robots in the form of machines autonomously moving around in space started making their way into homes in the beginning of the 2000s with vacuum cleaning robots [5]. Household robots are qualitatively different from traditional household appliances. Tools for home maintenance and cleaning are often kept at specific locations in the home from where they cannot move by themselves. An inherent quality of something stationary is that you decide where it goes, and it stays where you place it. Conversely, the mobile nature of a domestic service robot as it autonomously navigates the home gives the robot an element of ubiquity and sharing a domestic space with them is not without problems [6].

Historically, the way humans perform work has always evolved, from the very first technological advances such as knives and spears, through wash buckets and steam engines, to present day laptops and kitchen appliances. However, one common factor with technological advances is certain tasks become *easier*, but work never really disappears [7]. The work itself only changes forms as new technologies are introduced into our lives. A new tool requires maintenance to keep working and creates room for other tasks by allowing higher speed and precision. A vacuum cleaning robot does not create a void of work where you once had the traditional vacuum cleaner; the work associated with keeping a clean house merely changes form—just as it did when the traditional vacuum cleaner replaced the wash bucket and mop.

Because the human-robot relationship is different from other human-computer relationships [8], we must develop a different understanding of other technologies. As a technology for keeping a clean house, the ubiquitous nature of the technological space of domestic robots overlaps with the entire physical and social space of the home. Much research has been done on understanding how we accept robots as a part of the household [8]–[11]. However, there is not much research that examines *how* space is shared; what are the changes in practices that will eventually lead to acceptance or rejection of the robot. In this paper, we introduce a framework for understanding how tasks and task distributions (practices) change as robots are introduced into an environment.

This paper's contribution is to introduce the *Robot Facilitation Framework* to classify stages of facilitation of robots. We introduce the framework and its components: *pre-*, *peri-*, and *post-facilitation* that are the result of our analysis of our case studies. We start by looking at related work (Section II). Then, we present our method and three case studies that helped form our framework (Section III). In Section IV, we present our framework and its components. In Section V, we apply the framework to the cases of robots being introduced into homes from the studies in Section II. We find that the Robot Facilitation Framework does not replace other frameworks in human-robot interaction, but provides a new way to understand use of robots. We also discuss the relationship between the different types of facilitation. In Section VI, we provide our conclusion and opportunities for future work.

II. RELATED WORK

There are a few long-term studies of service robots in domestic settings. These focus on how and why people accept robots into their homes over time and use different frameworks for doing so.

Forlizzi and DiSalvo [8] use an ecological approach for determining how mobile, autonomous robots might fit into the domestic space, and how they differ from traditional vacuum cleaners. “The difference of physicality, autonomy, and mobility calls for a re-thinking of the experience of technologies in the domestic environment” [9]. They emphasize that robots and household members should be able to adapt to each other.

Looking at the social experience people deveplop around the use of a product (*product ecology*), Forlizzi [12] shows how robots, like other technologies, become social products as they are accepted into the home. In a product ecology, the environment affects how the product is used, and in turn, the use of the product itself changes the users and the context as a result. The products in the ecology simultaneously shape roles, social norms, human behavior, and how other products are used. There are five dimensions to understand how a product influences the product ecology: *functionality*, *aesthetics*, *symbolism*, *sociality*, and *emotionality*. These can in combination or individually start a process of sense-making, linking the familiar to the unfamiliar [12].

Forlizzi’s study [12] compared the adoption of a traditional vacuum cleaner and a robotic one and found that the robotic vacuum cleaner caused a change in the product ecologies in the household while the traditional did not. The Roomba had a substantial and lasting impact on people, activities, and the use of other cleaning products within the product ecology.

Inspired by Forlizzi’s use of the product ecology, Sung, Guo, Grinter, and Christensen [8] developed the Domestic Robot Ecology (DRE). This framework provides a holistic view on long-term interactions with robots and thus people’s long-term acceptance of them. It looks at how people’s attitudes and interactions towards robots change over time, especially as the novelty of the robot wears off (*the novelty effect* [13]).

The DRE has several dimensions. First, there are four temporal steps householders experience during their robot acceptance: (1) *pre-adoption*, (2) *adoption*, (3) *adaption*, and (4) *use and retention*. Second, there are three roles for the robots during this time: (1) *a tool to complete tasks*, (2) *a mediator to incur changes in the environments*, and (3) *an actor to elicit social responses*. Sung et al. combined these and presented three key aspects for how robots interact within all the four temporal steps, taking on one of the three roles. These aspects are: (1) *physical and social space*, the platform where the interactions can take place; (2) *social actors*, the living members of the home, such as householders, guests, and pets; and (3) *tasks*, the activity the robot is designed to serve. Thus, five types of relationships can occur, where the robot can be *a tool* to perform tasks, *an agent* directly impacting the surrounding environment, *a mediator* that motivates people to make changes to the environment, *a mediator* that enhances the social relationships, or *an agent* that engages with people in social events. With all these dimensions, the DRE provides a holistic view of the relationships that robots shape in the home and how these change over time.

Fink, Bauwens, Kaplan, and Dillenbourg [10] used the DRE to understand long-term adoption and acceptance of Roomba robots in the home.

III. METHOD

The study is based on multiple case studies [14]. We used a set of qualitative inquiry sessions in the investigation of robot facilitation. Each case consists of observations or multiple interviews. Case 1 is the Automated Ground Vehicles (AGV) at the hospital (Section III.A). In this case, we interviewed an operating manager on two separate occasions. Case 2 is the investigation of lawnmower robots (Section III.B). For this case, we interviewed two different owners. Case 3 is an ongoing study with older adults who borrow vacuum cleaning robots (Section III.C). This case is based on observations. The interview questions were open-ended and different in each case. But the questions *between* the participants in a case are the same. The interviews and observations was analyzed by coding interview transcriptions described in detail in Søyseth and Søyland [15]. As this was qualitative data, so statistics are unavailable.

A. AGV at a Hospital

There are numerous examples of robots within industry and organizations, but they are often found in separate and enclosed areas where only authorized personnel have access [16]. However, our informant told us that multiple hospitals have employed AGVs for several years to do most of the heavy-lifting transport tasks and thus decrease the need for human porters. These robots operate in the same areas as the hospital staff and thereby create an arena for observing spatial encounters between robots and humans.

Since 2008, a major Norwegian hospital has used an AGV system consisting of 22 robots. The robots have been in service for nearly ten years. This allows us to disregard the possibility of a novelty effect commonly caused by robots; the staff would regard them as commonplace.

The AGV robots require building structure and infrastructure to accommodate them. They follow magnetic markers embedded in the floor throughout their operating areas and use strategically placed charging stations. These infrastructure requirements were part of the planning and building process of the hospital. The robots operate mostly in the hospital basement where there are no unattended patients. A patient can only encounter a robot when it takes an elevator up to one of the hospital departments. Even then, the robots venture only a few meters into the departments to deliver their goods at a dedicated delivery nook.

According to our informant, the hospital administration initially assumed that the robots could operate almost entirely without supervision, needing only occasional checks by an operator. However, the hospital staff soon realized this was a flawed assumption. “If you leave the screen for 10 to 20 minutes, there is a standstill somewhere,” said our informant.

Furthermore, he explained how a single standstill quickly would result in cascading failure. This would eventually lead to a total stop of the system since the AGVs cannot pass each

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Figure 1: (*Left and center*) makeshift signs to tell people to leave the robot's nooks alone; (*right*) a more refined sign.

other. This highlights the importance of facilitating for seamless operation during the robot's working time.

Standstills can occur due to technical problems in the AGV themselves, but often it is "human error." Our informant described how the medical staff would leave all kinds of objects in the magnetic path or the delivery nooks of the robot. As the AGV has no way to make its way *around* obstacles, all obstacles are insurmountable. In these situations, the only solution is for an operator to find and remove the obstacle. To reduce the frequency of these standstills, signs had been put up throughout the hospital to inform people that the robots need a clear path to operate, reminding them not to leave anything in the hallways. Some of these signs look very professional and refined (Figure 1, right), while others have more of a makeshift look (Figure 1, left and center).

The maintenance and ongoing facilitation for the AGVs require three full-time employees. The employees' main task is ensuring the robots do not come to a standstill, working in shifts to always be present for robot monitoring. As mentioned above, the hospital had not expected the level of robot supervision required. The constant monitoring now carried out was not in the initial plan of the deployment strategy. Though the AGVs require a substantial amount of facilitation, their deployments give a net positive amount of work; they provide the same work as 15-25 full-time employees, based on between 400-500 assignments every day.

During the first two to three years of using the AGV within the hospital, three technicians from the AGV's manufacturer worked full-time on the implementation and configuration of the system, after which they considered the system stable enough for them to leave.

B. Robotic Lawnmower

In the case of the lawnmower robots, we interviewed two different individuals owning a lawnmower robot. Both robots were of the same brand and had the same functionality.

When the informants had set up the robot for their garden environments, the amount of setup work required help from family members. The preliminarily work of setting up the perimeter fence and programming amounted to between two to three days for each of the informants. This workload was *expected* by the users: They were informed in advance about what was needed to be done to set up the robots correctly.

However, both informants reported they needed to watch the robot during its working hours to make sure that it was not stuck somewhere. Moreover, they told us how they now kept their gardens clear of foreign objects, such as gardening tools, flowerpots and other decorations.

One informant had a diverse garden with steep hills, some steps making up a tiny stair, a sandpit from when her children were younger, some berry bushes, a flowerbed, an apple tree, and a large tree stump. Most of these obstacles created more work in facilitating the robot's work than she and her husband had anticipated. For instance, during late summer and early fall, apples fall from their apple tree, the fallen apples often caused the robot to stop altogether. Our informant reported picking apples off the lawn every morning to help the robot complete its job.

Furthermore, it was difficult for the robot to access all parts of the garden. In most of the accessible places, it would often get stuck. Our informant described an issue revolving around her robot's ability to get up the steep hill and the placement of the tree stump. The stump sat just at the top of the hill, right where the ground flattens out. To climb the hill, the robot needs momentum. The robot cannot see, and it can only detect obstacles by bumping into them. So, it can never plan its trajectory with these obstacles in consideration and simply moves in a randomized pattern. Thus, whenever it hit the tree stump, it would lose momentum and get stuck. This happened nearly every day and occurred more frequently on rainy days.

Since the robot getting stuck and disabling it from carrying out its task was inconvenient, the informant and her husband decided to remove the tree stump (Figure 2). She was uncertain whether she and her husband would have removed the stump if they did not have the robot: She found the stump charming, and had imagined placing flowerpots on it.

She had also contemplated removing the apple tree, but so far, she has not taken this measure as she has some regrets over removing the tree stump. Removing the apple tree, like removing the stump, is an irreversible action.


Figure 2: (*Left*) the tree stub being chopped up and removed, and (*right*) the robot going down the hill

C. Robotic Vacuum Cleaner

Setting up a robotic vacuum cleaner is a smaller job than setting up a robot lawnmower. Its navigational technology does not require a perimeter fence to move within the domestic environment. The process varies between brands and is a little more complicated if the user decides to use the smartphone application, but the only *required* set up by the user is placing the robot's docking station.

In our study, we provided a robotic vacuum cleaner to five older adult participants living independently in their own apartments. Most participants did not have wireless internet or a smartphone, and could thus not use the smartphone app, making set-up in their apartments easy.

While robotic vacuum cleaners can run without the supervision of human operators, most participants did not trust the robot to run while they were not home. They preferred to keep an eye on the robot during its operation time to prevent it from getting stuck or accessing unwanted areas.

IV. FINDINGS

We have seen how all the robots we have investigated altered existing tasks and added new ones for them to operate properly. Further, we saw that the tasks varied widely; from small alterations in the operational environment, through continuous tidying tasks, to substantial infrastructure modifications. We call all such tasks *facilitation*. After examining the tasks, we saw that the tasks begin to coalesce in some categories: *pre-facilitation*, tasks done before the robot can operate; *peri-facilitation*, tasks done while the robot is operating; and *post-facilitation*, larger tasks done after the robot has been deployed a while that reduce peri-facilitating tasks.

A. The Robot Facilitation Framework

The Robot Facilitation Framework helps designers understand *how work changes*. Its central idea is understanding how the introduction of robots change tasks and task distribution. The framework describes how we share space with a robot, rather than describing how we accept robots into our space. The framework has three components.

1) Pre-facilitation

The first kind of facilitation in our framework takes place right before the deployment of the robot. We call this *pre*-facilitation. The user makes the changes both necessary for the robot to start, as well as alterations they think will merit the robot's operations. Often, facilitation is required for starting the robot, such as the placement of a docking station and fence cable. Other changes to the environment are made because the user assumes the facilitation will accommodate the robot, for example, removing power cords to avoid tangling.

2) Peri-facilitation

However, the changes made in pre-facilitation are rarely sufficient. The technologies in today's robots require an uncluttered operating area, which is rarely found in domestic settings [17]. Consequently, to facilitate a smooth operation period for the robots, humans need to continuously tidy. We have discovered some required tasks might come as a surprise to the user and are not easy to anticipate such as picking up apples. As robots today cannot take care of and repair themselves, users also need to perform maintenance on the robot. Maintenance activities include changing the blade on the robotic lawnmower and changing the brushes of the robot vacuum cleaner, as well as larger maintenance tasks as done by technicians from the manufacturer that delivers robots in systems such as AGV found in the hospital.

We call this *peri*-facilitation because the tasks are required continuously during the robot's operational time. The bulk of time one used to spend doing the tasks now performed by the robot is replaced with smaller tasks requiring a few minutes every day. The tasks are performed by the user to make sure the robot operations run smoothly, such as removing clutter to prevent it from getting stuck, assisting it should it get stuck in or under something, and all time spent on robot maintenance. In other words, peri-facilitating tasks are a form of everyday maintenance.

3) Post-facilitation

As the users find recurring patterns for facilitation required during the robot's operations, they can decide to make bigger changes to their environment—such as removing a tree stump—as a way of reducing the need for peri-facilitation. We call this *post*-facilitation. A thorough understanding of how the robot operates in the specific domestic settings is required to make post-facilitation changes.

V. DISCUSSION

In Section II, we briefly presented a few long-term studies of service robots in domestic settings. These studies focused mainly on how and why people accept these robots into their homes over time. The product ecology and the Domestic Robot Ecology have their focus on *acceptance* of robot technology. Our framework is a supplement to other frameworks on understanding use of robots.

In this section, we compare the Robot Facilitation Framework to the Domestic Robot Ecology and product ecology. The Robot Facilitation Framework looks at how work changes with the introduction of a robot. The Domestic Robot Ecology and product ecology look at adoption and acceptance, but both possess elements that fit within the Robot Facilitation Framework. Finally, we discuss the interrelationship between the three categories of robot facilitation.

A. Robot Facilitation Framework in Other Cases

Sung et al. [8] describe robot acceptance as happening in four temporal phases. In the pre-adoption phase, the users form their expectation of the robot. Because the Roomba requires nothing but placing the docking station before it can start, users with high expectations of the robot perform little to no pre-facilitation. When little pre-facilitation has taken place, the robots could cause accidents. Whenever the Roomba caused accidents, the participants in their study made changes to the environment necessary to prevent the same accident from reoccurring: "Some of the actions included casual and temporary changes that they needed to repeat in each operation. Other changes were more permanent" [8] The more temporary changes were things like folding area rugs, blocking Roomba with objects, and picking up clutter. The changes considered more permanent included things like placing books under lamps to prevent Roomba

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from climbing it, or removing rug fringe to prevent it from getting stuck. These are good examples of both peri- and post-facilitation.

Forlizzi and DiSalvo [9] point out that the Roomba's need of a clutter-free environment caused some participants to engage in what they refer to as "pre-cleaning activities." By doing some pre-cleaning, the home environment was ready for Roomba to do the cleaning without supervision. They describe this as an "unusual dynamic between the product, the physical environment, and the participant" [9] where the participants must decide when they should intervene during the Roombas operational activities. Though there are few concrete examples described here, the problem area as described where the functionalities of the Roomba lead users to accommodate the robot's operations is the basis for peri-facilitation and key to understanding the processes around this type of facilitation.

Fink et al. [10] observed that their participants made changes to the environment that was encouraged by the robot. They also describe how participants spent different amounts of time on adjusting the space before turning Roomba on, and that some households had to solve further issues such as moving away delicate objects. In their study, participants expressed not wanting to let the Roomba work by itself at home while they were out, illustrating the need to be there and peri-facilitate should Roomba crash, get stuck, or other unforeseen peri-facilitating tasks. They further describe how participants, children especially, would assist the robot by collecting crumbs and placing them directly in front of the robot, or build walls out of obstacles.

Cesta, Cortellessa, Orlandini, and Tiberio [11] examined a telepresence robot in the home of an elderly couple over a year. The study had both pre-facilitation to prepare for the robot's arrival and peri-facilitation as the robot was in use. Since the study had a known end, there was no post-facilitation, but the suggestions from the couple about where the robot should be placed when charging indicate that post-facilitation would be needed for the robot to be used after the study.

B. *Interrelationship between the types of facilitation*

Setting boundaries for categories based on qualitative data is rarely clear-cut. When analyzing human-robot observations through the Robot Facilitation Framework, we find that some actions of facilitation are hard to place completely within one of the three categories. Should the three categories be considered as *types* of facilitation, *stages* of facilitation, or *phases* of facilitation?

In the following, we discuss the relationship between these categories, as illustrated in Figure 3. The solid arrows represent how the process of facilitating for a robot evolves. A pre-facilitation task would be finding a spot for the docking station, and setting it up. As the robot works, emptying out the robot's dust bin would be a peri-facilitating task. Upgrading the infrastructure to increase the usefulness of the robot is a post-facilitation task, which leads back to peri-facilitation as the robot works in the new environment.

However, some relations are more uncertain than others. These are marked by dashed arrows and question marks.

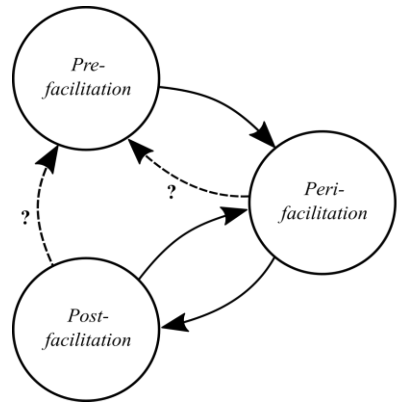

Figure 3: Interrelationship between the three facilitation categories

These uncertain relations raise questions such as "can one move from peri- and post-facilitation to pre-facilitation, or does pre-facilitation only happen once during the deployment of the service robot?" We need to decide what actions should be considered pre-facilitation. For instance, can pre-cleaning activities, as described by Forlizzi and DiSalvo [8] take place after the deployment of the robot, but not during its operational time? In the view of the Robot Facilitation Framework, should activities performed during the deployment period of the robot, but not when it is *currently active* be considered a *pre-* or a *peri*-facilitating task?

As we saw in the example of AGV, the infrastructure of the hospital tied to the deployment of the robots was planned during the construction of the hospital itself. Ozkil et al. [18] examined what was needed to implement service robots in a Danish hospital, a process which can be understood as pre-facilitation of robots.

This shows that pre-facilitation can be a huge process, starting already when planning a building, or it can be next to nothing should the user not feel the need to change anything in their domestic environment before they start the robot. Indeed, it seems that the extent of the pre-facilitation can vary greatly, and to some degree depend on the complexity of the environment it will be operating in, as well as its infrastructure. From our analysis, pre-facilitation sets the foundation for which new tasks arise as part of peri-facilitation when the robot is operationally active. Next, depending on how cumbersome the peri-facilitating tasks are, as well as their persistence and recurrence, will determine what measures will be taken to avoid these in the future. When changes are done to avoid certain peri-facilitating tasks, the users have post-facilitated their robot. What is unclear when it comes to the relationship between the stages, is whether the user after such a change finds themselves doing pre-facilitation again, or if they find themselves right back doing peri-facilitation.

Finally, how big is as post-facilitation change? Are only irreversible changes eligible post-facilitating actions, or can smaller one-time actions that could easily be reversed fit into this category? Irreversible changes include hiring full-time workers to look after the robot, removing a tree stump so the lawnmower can get up the hill, or replacing a floor lamp with a wall-mounted lamp so that vacuuming is easier. A reversi-

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ble change would be placing a book under a lamp to prevent the robot from climbing it.

Tying all these questions together, we see that the answer to one of them will have consequences for the others. If placing books underneath a lamp is not post-facilitation because it is not irreversible, it must be either pre- or peri-facilitation. If peri-facilitation can only take place while the robot is running (except whenever the user is doing maintenance *on* the robot), then it must be pre-facilitation. However, if we define pre-facilitation as something that only takes place *before* the deployment, then it must be either post- or peri-facilitation after all. Is it important for the framework that post-facilitation actions are recognized as something big and irreversible? Similarly, is it important for the framework to recognize pre-facilitation actions as only taking place before the deployment of the robot?

VI. Conclusion and Future Work

Our study consisted of multiple case studies, considering human-robot interactions at a Norwegian hospital, in the gardens of two robotic lawnmower owners, and observations of elderly deploying robotic vacuum cleaner for one month. We found that work did not disappear, but that tasks were redistributed. We presented the Robot Facilitation Framework that divides facilitation into *pre-*, *peri-*, and *post-facilitation*. Using this framework, data collected from other studies can be understood in a different light, focusing on how work changes when robots are deployed. The categorization simplifies targeting challenges in the interaction between humans and robotic technologies. Moreover, it may also indicate specific design implications for what tasks should be put in which category. It also helps us to understand the amount of work that is included in introducing and keeping a robot in a location. This can help people to determine how best to introduce and use robots in new areas.

There is more that can be done with this framework. There is no precise answer to which activities belong to which categories. To make our categories and the relations between them more precise, we will carry out more studies of robots in use and analyze them. As a part of this, we will explore how facilitation relates to maintenance, performativity, and mediation, and how robot users experience to share their space with robots. This should make it easier for others to apply the framework in future scenarios where robots are introduced at work and at home.

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