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Human-Centred Design of Industry 4.0 Technologies in Research Projects

Susanna Aromaa, Päivi Heikkilä, and Hanna Lammi

VTT Technical Research Centre of Finland Ltd, 33101 Tampere, Finland

ABSTRACT

Novel technologies are often developed through collaborative research projects. This increases complexity in collaboration compared to company-internal development projects and can create challenges as regards applying human-centred design (HCD) principles to the development. This paper presents two research projects in which human factors (HF) had an essential role. Although HF principles served as a useful guide in the design of technology solutions, some challenges were encountered. These challenges are outlined in this paper and suggestions regarding how to manage potential risks in collaborative projects are presented. Lessons learned from these projects can be used by HF researchers in future research projects to better manage HF activities when developing technology solutions.

Keywords: Human-centred design, Co-design, Research project, Technology solution, Industry 4.0

INTRODUCTION

Digitalisation and automation are changing industry and require workers to apply novel technologies in their work (e.g., augmented reality, robotics and artificial intelligence) (Romero et al., 2016; Kagermann et al., 2013; Kadir and Broberg, 2020). During this transformation towards smart factories, it is important to develop Industry 4.0 technologies by applying human-centred design (HCD) approaches (e.g., ISO 9241–210, 2019; Brown, 2008) and ensuring participation of users (Ehn, 1993; Muller and Kuhn, 1993). These HCD approaches are well described and can serve as a valuable guide in the development process. However, technologies are not always developed within a single company or a small development group, but rather the first versions of technology solutions may be created in collaborative research projects.

The development of technology solutions in research projects may increase complexity in collaboration and create challenges as regards implementing HCD principles. For example, in the smart construction sector, it was noted that using a design thinking approach in a research project was not a simple and straightforward task (Aromaa et al., 2022).

The goal of this paper is to understand the main challenges that can hinder the use of HCD principles during research projects aimed at technology development. This paper describes the challenges encountered in the application of HCD during two research projects. First, the paper describes the research projects and how the challenges were identified (Material and methods).

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Then it describes the challenges encountered (Results) and how the main challenges could be managed during the projects (Lessons learned). Finally, conclusions are presented.

MATERIAL AND METHODS

This section describes how the challenges were discovered and provides short descriptions of two research projects. The challenges were identified by three human factors (HF) researchers who participated in the projects: all three of them participated in the EU-funded project and two of them participated in the nationally-funded project. They all work in the same research institute, and they have over 20 years of experience in HF research in different kinds of research projects. After the projects ended, the HF experts had a workshop in which they identified challenges they had come across during the projects. To identify these challenges, they adopted the HCD process description from ISO 9241–210 (2019), which has main four steps: (1) understanding and specifying the context of use, (2) specifying the user requirements, (3) producing design solutions, and (4) evaluating the design of the approach. The HF researchers discussed challenges related to these four phases of HCD.

The first project was a four-year EU-funded project, in which 20 partners developed human-centric industrial applications to support modern industrial work. The partners represented research organisations, technology providers and manufacturing companies as industrial pilot organisations. There were three different partners who focused on HF research. The project was carried out from 2020–2023. The aim of the project was to find the balance between cost-effective automation and involving human workers in tasks where they create the greatest added value. The HF work focused on studying industrial requirements for the development of the new components, co-defining industrial use cases, giving human-centric design and research guidance to the partners, evaluating the developed components and co-creating ethical guidelines within the consortium.

Another project was a nationally funded co-innovation project that was conducted over two years (2021–2023). Nine companies in the fields of robotics solutions, software and B2B services, and a research institute participated in the project. Researchers from the institute represented three different research areas: business, robotics and HF. The aim of the project was to study new technologies and multi-purpose robot-enabled services and business models. The scope of the project focused on autonomous, mobile service robots that are used indoors or outdoors, for instance, in last mile deliveries, maintenance, surveillance and customer service. Concerning HF, the focus was on the development and evaluation of the user experience and acceptance of shared, heterogeneous multi-purpose service robots and robot fleets.

RESULTS

Human factors were an essential part of both research projects assessed and beneficially affected the technologies that were developed in the projects. However, the HCD activities could have been better organised and managed

during the projects. Based on these two projects, it was found that there can be challenges in all four HCD phases when designing technology solutions in a research project. The following sections describe the challenges identified in the projects.

Challenges Identified in the EU Project

This project involved 20 partners from all over Europe, three of which focused on HF topics. Therefore, it took some time in the beginning to get together with all the partners, agree on responsibilities and create a common understanding of the project's goals and the tasks that needed to be performed. Additionally, the abstraction level of the discussions was high in the beginning, and it took time to reach a precise understanding as to how to proceed in the project. At the beginning, a workshop was held in which initial requirements were ideated together, but it was challenging because there were several different development targets, such as technology solutions, support tools, pilots, use cases and a marketplace. Therefore, the requirements that were defined were general and the abstraction level was high.

In the HCD phase, in which a context of use is defined, the project faced challenges because the coronavirus pandemic restricted travel and it was not possible to see industrial contexts in real life. Additionally, during this phase, the understanding of the use cases was formed by interviewing mainly project partners and other stakeholders (and not actual end users). These interviews were also used to define the specific requirements for each use case. In some companies, the definition of use cases took time and some of the cases changed completely from the initial plan. This meant extra time was needed, and this delayed other actions, such as the planning of HF evaluations.

When the use cases and technology developments were more defined and prototype building had started, one challenge was that the requirements were not systemically reviewed and refined to support this more detailed level of prototype design. Development actions in the project were carried out by several distributed partners and, therefore, the HF experts were not able to be intensively involved in all technology development cases. This led to challenges as regards following the co-design principles, and only rather general HCD guidelines were created to guide the developers.

Human factors evaluations during the project were conducted mainly on an independent basis by the pilot partners, and the HF experts only provided data collection material and received results from the pilot partners for analysis. The HF experts were not able to follow the actual tests or have direct contact with end users. This also meant that only quantitative (questionnaire) data were gathered and more qualitative (e.g., observations, interviews) were not extensively obtained.

Challenges Identified in the National Project

This project had similar challenges at the beginning, when seeking to redefine a common goal for the collaboration and create a shared understanding of the

"multi-purpose robot" concept. Another challenge was due to the fact that versatile fields of robotics were included in the project (indoors/outdoors, maintenance, delivery, surveillance, customer service) and therefore it was not possible to define common HF requirements and principles that cover all robots, e.g., in the form of heuristics. Interviews related to understanding the context of use were conducted by business researchers who reported the results to the project group. However, HF researchers were not involved in defining the interview questions and therefore were not able to comprehensively gather insights important to their research. The project focused on innovating new business and service models for multi-purpose robots and actions thus focused more on technology development and service models than on the interaction with humans (end users).

The project encountered resource challenges, notably due to time constraints on the part of the technology developers. For example, the project attracted a lot of interest in the media and among the public: demos were requested, and their design and implementation ate up resources. Consequently, collaborative efforts with the HF experts were limited. Another challenge was that the work was somewhat siloed because companies had their own development goals and other technology developers had theirs.

Because the project focused heavily on technology development, there was a technology feasibility study arranged. However, the planned final pilot with robots was first postponed and finally cancelled. Therefore, the HF experts were not able to evaluate the multi-purpose robots with actual end users and customers.

LESSONS LEARNED

This section summarises the main challenges when applying the HCD approach identified in the two research projects presented (Table 1). Additionally, it describes ways of mitigating the possibility of these challenges arising or negatively affecting the research results. One of the main challenges was that there was not enough time and effort allocated to defining a common understanding of the project and its goals at the beginning. Consensus regarding how to collect data to understand the context of use and how to share findings should also be thoroughly planned and executed in collaboration. The definition and management of user requirements needs more attention, especially when moving forward in research projects. It is important to understand for whom requirements are defined and how to refine them during the project. When producing design solutions, collaboration and information exchange should be emphasised, especially between HF experts and technology developers. Final pilot evaluations can often be planned for the end of the project due to the time reserved for technology development. This is a managerial issue that a project leader should recognise and then take steps to ensure the timely development of prototypes or provide other ways to substitute prototype evaluations (e.g., by using Wizard of Oz method (Kelley, 1984), in which not all technology features need to be implemented). Additionally, the project leader should advance collaboration between end user companies and HF experts to ensure access to real users.

Table 1. Summary of challenges identified when implementing human-centred design in two research projects and possible ways to manage the risk of the challenges arising.

Human-Centred Design Phase (ISO 9241-210, 2019)	Main Challenges Identified	Possible Ways to Manage Risks
Understanding and specifying the context of use	Defining common goals and understanding for the project	When writing a project plan, allocate more time and effort to co-creative activities in which common understanding and goals can be defined.
	Involving all partners in understanding the context of use (gathering data and sharing information)	Plan data collection activities together, collect data that is important for different partners and define data sharing strategies.
Specifying user requirements	User requirements remain at a general/high level –requirements are not refined while going further in the project	Outline in the project plan how requirements are to be managed, and at what point they will be reviewed.
	User groups are not yet known and/or access is not allowed (requirements are based only on project partners)	Try to identify users and other stakeholders at the beginning of the project. Additionally, re-define requirements during the project, when the research work becomes more defined.
Producing design solutions	Design solutions are created in silos	Provide means and ways to make technology development more transparent (e.g., arrange workshops, meetings, demos while development is happening).
	HF experts are not involved at this stage	Include in the project plan that co-design principles should be applied throughout the project. Be clear in the beginning that HF experts need to hold discussions with solution developers.
Evaluating the design	Final pilots with end users are late or cancelled (focusing only on technology feasibility)	Highlight this risk at the beginning of the project to all partners. To mitigate the risk, arrange small experiments during the development process. Additionally, plan how to use substitutive methods (e.g., Wizard of Oz method) to execute HF studies if technology is not ready.
	HF experts do not have access to end users	Be clear as to who the end users are and who are other stakeholders. Highlight the importance of collaborating with real users. Define alternative plans to substitute end users, if they are not available and if HF experts are not able to meet them.

CONCLUSION

The use of human-centred design (HCD) approaches supports the design of good usability products that are accepted by users. This paper presents two research projects in which human factors (HF) were an essential part of the development of technology solutions. Even though HF principles were successfully taken account in the development, there were some issues that hindered the HCD process. To learn from these matters, this paper identified challenges in applying HCD principles in research projects.

Key findings for HF researchers to keep in mind in future research projects are that a project leader should be well informed about the HCD process and that there should be enough time set aside at the beginning to create the basis for collaboration and common goals. Additionally, specifying user requirements at the beginning of the project is not enough; it is equally important to manage and refine them during the project. Timely evaluations are also essential in research projects, and if this is not achieved, HF researchers should have back-up plans to ensure that HF topics are addressed. These lessons learned can be used when designing human-technology interaction in collaborative projects with different stakeholders.

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