Design as a Practice in Human-Robot Interaction Research

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Abstract

This chapter reflects on the scope, methods, knowledge contributions, and normative orientation of design for the research field Human-Robot Interaction (HRI). The design space of interactions between humans and robots is characterized as being influenced by the way interaction is understood. Underlying views of interactions merit consideration, as they influence the research questions, methods, and aims of HRI design research. It is argued that we need to understand the concept of the design space(s) for HRI as extending beyond individual aspects that can be varied in the design of interactions between humans and robots to encompass the socio-technical system that the robot is developed for. This chapter further characterizes the practice of HRI designers as comprising multiple overlapping activities, operating in a complex problem context in a design team with multiple sets of expertise from different disciplines, comparable to or functioning as transdisciplinary research. This chapter contains a discussion of knowledge contribution that can be achieved through design practice and concludes with reflections on the responsibility of designers.

Keywords

Human-Robot Interaction, Interaction Design, Design Research

1 Introduction

Human-Robot Interaction (HRI) is a multidisciplinary research field that integrates disciplines such as engineering, psychology, sociology, philosophy, and more[1]. Collaboration between different disciplines is necessary to achieve goals (such as developing robotic systems for human-aware navigation), but can be complicated as each discipline has a different jargon, uses different methods, and knows different practices and paradigms. Design is frequently described one of the disciplines of relevance in HRI. Lupetti et al. define designerly HRI as "*the body of work in HRI that has a strong orientation toward design (i.e., work developing novel robotic artifacts and/or engaging with design methodologies)*" [2021, p. 389]. They consider designerly HRI as a methodology or form of research, a "means for investigation" [Lupetti et al. 2021, p. 381] extending beyond individual robot designs or designed features. As it is necessary to collaborate across disciplines, this chapter aims to further clarify the role of (interaction) design in HRI and how it contributes (both in terms of knowledge and prototypes) to HRI research and the development of robotic systems.

This chapter is a position statement and literature review on the scope of the HRI design practice, activities that are part of design practice, the potential of design to contribute knowledge, and the normative orientation that design work

1 Key characteristics of disciplines include that they have a specific focus on certain phenomena, concepts, methods and theories, and that they subscribe to particular 'rules of the game' and specific disciplinary perspectives [Szostak et al. 2016, p. 10].

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implies. Whereas design of robot appearances and behaviors for interactions between humans and robots has been a topic for several decades (see for instance the special issue on design for HRI [Holmquist and Forlizzi 2014] and work on social robot embodiment design and anthropomorphism [Blow et al. 2006; Hegel 2013; Deng et al. 2018]), and to an extent design methodology (for instance [Bartneck and Forlizzi 2004; Drury et al. 2004], and work on Value-Sensitive Design [Dignum et al. 2018; Van Wynsberghe 2016; Cheon and Su 2016]), recently there is an uptake of interest in reflecting on design methodology for HRI and how design research can contribute knowledge to the HRI community. This is exemplified by a series of recent papers and workshops on topics such as designerly HRI [Lupetti et al. 2021, 2020], integration of User eXperience (UX) design in a human-robot interaction design workflow [Prati et al. 2021], use of metaphors to inspire HRI design [Alves-Oliveira et al. 2021], combination of UX design and ethics in the design of social robot behavior [Fronemann et al. 2021], Research through Design (RtD) [Luria et al. 2021], exploratory prototyping for HRI [Zamfirescu-Pereira et al. 2021], and Design-Centered HRI and Governance [Weng et al. 2021]. Questions relevant to these workshops and papers include what an HRI design epistemology could be, evaluation of knowledge resulting from HRI design practices [Lupetti et al. 2020, 2021], and reflection on which RtD methods are relevant for HRI [Luria et al. 2021]. The recent interest in design methodology, design practice for HRI, and the necessity to collaborate across disciplines in HRI make the topics of design practices and design knowledge both timely and relevant.

This chapter references work in Human-Computer Interaction (HCI) and theory on design research that is relevant for HRI designers, as there is a certain maturity in those discussions that will be informative. This chapter seeks to answer several questions: why is design relevant for HRI? What can it be useful for? What do designers know or what can they do that can contribute to solving problems? Why is design positioned (perhaps uniquely positioned) to solve specific problems?

This chapter discusses the concept of design space(s), characterizations of the practice of designers, and characterizations of knowledge contributions that design can offer. It reflects on the ways of thinking about the activity of designing as part of an HRI research practice. Finally, the chapter argues that responsibility is inherent to the design practice as a result of one of the main aims of design, namely to change or impact people, societies, and the world.

2 The Design Space of Human-Robot Interactions - From the User Interface to the Socio-Technical System

2.1. The Concept of the Design Space

In this section, we discuss various levels at which we can consider design. What can designers affect? What is part of the "material" of a designer's practice? One concept we can start with is that of the design space. A design space can be described as the set of possible design alternatives or aspects of a design that can be altered. The term design space is frequently used to indicate that the design problem, object or system has various features that can be varied: design decisions have to be made regarding these features. The concept is commonly used in computational design, and it is gradually making its way into HRI as a way to describe a design problem.

Halskov and Lundqvist elucidate the concept of design spaces in a HCI context: *" (...) a design space may be represented in a number of ways, such as a Cartesian space, a network graph, or a conceptual space. The scope of a design space ranges from a class of technologies, over all accumulated knowledge during a specific design process, to the design space of a collection of designs, ideas, and sketches."* [2021, p. 3]. They note that the term design space can refer to the physical space where design activities take place. Thinking of a design problem in terms of its design space can also take the specific form of representing design aspects computationally, with requirements that need to be satisfied represented as objective functions that need to be optimized. Design space exploration refers to the idea that a large space in which designs are represented in a specific way can be traversed computationally [Woodbury and Burrow 2006]. Computational methods for exploring the design space can be useful for finding a solution that satisfies design objectives while exploring more of the design space. It assumes that the problem can be modeled as a combination of parameters to be adjusted to satisfy constraints [Chan et al. 2022]. A computational approach to the design space concept can be useful for restricting the problem scope and finding new design solutions within said restricted problem space. However, certain requirements or constraints are not easily (or at all) possible to represent as an equation or numerical condition/value that can be met. These operate at different levels, e.g. in interaction with one or multiple users, or only become apparent when the technology is introduced to society on a large scale.

The design space term can also refer to a metaphorical space containing possibilities and alternatives that are taken into consideration to satisfy design requirements [Halskov and Lundqvist 2021]. Botero et al. describe the design space as “*the space of possibilities for realizing a design*” [2010, p. 1] and “*the space of potentials that the available circumstances afford for the emergence of new designs*” [2010, p. 3].

In the context of HRI, the design space term is often used in its conceptual or metaphorical sense. Deng et al. [2018]. describe the design space in terms of changes that can be made regarding the appearance, behavior, and structure of interactive technologies such as social robots. Baraka et al. [2019] propose a framework with seven dimensions for characterizing social robots, which they describe as forming a design space. The framework contains the following dimensions: appearance, social capabilities, purpose and application area, relational role, autonomy and intelligence, proximity, and temporal profile. The design spaces sketched by Deng et al. [2018] and Baraka et al. [2019] have a strong focus on the robot as a socially interactive device with a specific appearance and function. Other frameworks have been developed for describing HRI. Goodrich and Schultz [2007] describe the dimensions that HRI designers can affect (autonomy, information exchange, team structure, adaptation and learning, and task shape) with a focus on human-robot teamwork. In the HCI context, Forlizzi and Ford [2000]’s design framework of user-product interaction includes the user, the product, context of use, social and cultural factors. On the human side they include the factors emotions, values and prior experience; on the product side they include aesthetic qualities, form language, features, and usefulness.

2.2. Interaction Design, UI & UX

In discussing the main topic of design for HRI, the focus of the current chapter is on interaction design, that is, designing for interaction. Interaction design has been described as “*the shaping of digital materials — software, electronics, telecommunication, etc. — with a particular focus on the use of the resulting digital artifacts*” [Löwgren 2007, p. 1].

An interaction designer affects the appearance of a system, its behavior in response to stimuli, and the quality of interaction and User eXperience (UX) in a way that fits the context, with the aim to improve a current situation by changing existing systems and creating new systems [Smith 2006; Fallman 2008; Goodman et al. 2011]. A host of aspects can be considered; the control method, the usability of the user interface (UI), familiarity, timeliness and correctness of action execution by the system, clarity of communicative cues used by the system, how well the system recognizes human cues, which cues the system can recognize, information quality, the embodiment of the robot, aesthetic qualities, and so on. Interaction design can be considered at different levels, from the micro level of button clicks on a graphical user interface (GUI) to the macro level of societal effects of technical systems. Although the scope of a design project may be restricted to, for instance, certain aspects of embodiment design, we would consider it of high importance that the setting that the robotic system is designed for, as well as broader ethical and societal implications, are taken into account during the design process.

First, the ‘micro’ level of human-technology interaction will be discussed here, by starting with the classical HCI design topics of UI and UX design before expanding the discussion to include a broader perspective on designing interactions, to argue that all these levels need to be considered in the design of technical systems such as robots.

To start off, we consider the UI. User interface design is highly relevant when discussing the topic of designing interactions with technical systems such as robots. UIs have been described as components or mechanisms that enable two-way human-machine communication, presentation of information, and human control of systems and processes to achieve specific tasks [International Organization for Standardization (ISO) 2010; Marvel et al. 2020]. The UI can also be described as all the means of input and output that offer humans interacting with the system the possibility to obtain information from a robot and affect the technical system across different modalities. This can include a GUI, motor sounds, gestures, sound alerts, and movement. Applying the concept of the user interface as familiar from other interactive technologies such as computers and smartphones is problematized in the case of HRI [Frijns et al. 2021]. Especially in the case of co-located robots, a human interacting with a robot will gain information from the robot via many other channels than just a GUI or other parts of the system that have been intentionally designed to convey information to an end user and allow an end user to act on the robotic system, as the embodiment of the robot and the way it moves and sounds (perhaps even smells and tastes) are informative and can be impacted.

Conceptually, restricting the UI to the input/output devices or mechanisms specific to the system renders the interaction rather flat, as interaction can never be just restricted to operations on the UI - the interaction is connected to the person, system, situation, and the world in addition to those specific input/output mechanisms employed in the UI. Consider for instance the concept of so-called *intuitive* use, a process that involves prior, partially automatic nonconscious knowledge (familiarity) [Naumann et al. 2007]. To achieve such a high level of ease of use, the design of the UI has to appeal to previous knowledge of the user, in other words, it should appeal and be connected to culture, prior experiences, motor memory, and so on. As soon as we talk about designing a UI, or consider a UI in interaction, we need to take the broader context into account, including one or multiple users, other people (including other stakeholders), objects, and technologies.

Where the UI is conceptually restricted to the input/output aspects of an interaction and information exchange, the concept User eXperience (UX) is intended to cover the more experiential aspects, which still leaves some space for considering the whole experience of the system as well as unintended inputs and outputs, such as motor sounds, which are generally not intended to be part of the UI but do provide information to an end user. UX can be described as part of the design space of human-robot interactions, focused on the experience of interaction of an end user. Perceptions and understanding of and responses to (anticipated) use of the system, suitability to the context, and how the system serves human needs are seen as part of UX [International Organization for Standardization (ISO) 2010; Weiss et al. 2009]. Taking UX into consideration as part of the design space of social robots already accounts for more aspects than just looking at operations on a UI, but in focusing purely on the user and their experiences, it is clear that more aspects need to be considered when designing HRI systems - other effects and actors not considered in the UX concept.

2.3. Waves of HCI and Views of Interaction

The different ways of approaching the design space of interactions between humans and robots depend on the ways interaction itself is viewed. Harrison et al. [2007] discuss Kuhn's concept of the paradigm shift, and argue that similarly, HCI is characterized by paradigms that are dependent on the paradigm's metaphor for interaction. These metaphors influence the goals for the interaction, research questions that are asked, and the methods used. Consequently, research that is conducted with different foundational views of interaction subscribes to different epistemological bases.

In the HCI community, several shifts in focus and thinking have been identified and described as the *three waves of HCI*. Work that is conducted within (or across) such ways of thinking is informed by particular views of interaction. During the first wave, cognitive science and psychology were adopted as a way to inspire technology design, with a focus on information processing, human factors and model-driven thinking. The second wave entailed a shift from disembodied single-user interaction to collaborative communities working in a particular context, but still with a focus on users, exemplified by for instance the use of participatory design methods. During the third wave the focus shifted to design-oriented, more exploratory, critical, value-oriented technology development for daily life acknowledging the importance of such things as complexity, experience, meaning, and emotion [Bødker 2015; Fallman 2011; Harrison et al. 2007; Frauenberger 2019].

The metaphors reported by Harrison et al. [2007] as central to each wave are interaction as [hu]man-machine coupling, as information communication, and as phenomenologically situated, respectively. Where most authors distinguish three waves, Frauenberger [2019] proposes a fourth wave called *Entanglement HCI*. According to Frauenberger, HCI researchers/designers cannot "*design interaction*"; instead, they work on "*configuring material conditions*" [2019, p. 12].

Several theories, frameworks and accounts have attempted to describe what happens in the interactions between humans and technology, for instance the Product Ecology [Forlizzi 2008], Actor-Network Theory (ANT) [Law 1992], Activity Theory [Bertelsen and Bødker 2003], distributed cognition, and computational rationality [Oulasvirta et al. 2022]. *Interaction* can be understood or framed in different ways, as demonstrated by Hornbæk and Oulasvirta [2017] and by Frijns et al. [2021]. For instance, interaction has been conceptualized in the context of HCI as dialogue, transmission, tool use, optimal behavior, embodiment, experience, and control [Hornbæk and Oulasvirta 2017]. Naumann et al. [2007] describe interaction as information and energy exchange. Interaction and communication in HRI can be described, for example, as the sending of signals, as communicative action, as joint action or as a dynamic system, and main ways of framing interaction include interaction as control and as social interaction [Frijns et al. 2021]. Besides dyadic models of HRI, the attention on non-dyadic interaction is increasing [Schneiders et al. 2022].

Inherent to describing a communication process is the consideration where the communication is "located", or the question who is participating. What is social here, the relation between a human user and one or multiple robots, the relation of a user to the system's designers/developers, or social interactions that the robot enables between other agents? We can describe this as *sociality in the artifact, sociality through the artifact, or sociality with the artifact*. Conversely, we may describe *sociality as located across a network*, as in ANT.

Breazeal [2003] and Fong et al. [2003] distinguish several paradigms for social HRI that range from robots being *socially evocative* systems to robots being *socially intelligent*. Such paradigms are exemplary of a view of *sociality residing in the artifact* or as being a property of the robotic system or a human's relation with the robotic system: the artifact relates socially itself.

Another view of the communication process is that of the designer(s) of a system communicating with the end user, *sociality through the artifact*. For example, De Souza [2005] proposes semiotic engineering as a theory of HCI that construes computer systems as messages that are sent from the interactive system's designers to its users. The system functions as a deputy of the designer. It speaks for the designer, and this is described as a metacommunication process

- the designer's message is unpacked over the course of the user's repeated interactions with the system. De Souza states that computer systems encode a problem and a specific solution to that problem. Through exploration and negotiation of meaning with the system, the user is able to apply the designer's vision creatively to new problem situations.

Technologies such as robots can also be viewed as serving a mediating role; *sociality with the artifact*, where the artifact enables social relations between other actors. Such a role is described in the Domestic Robot Ecology [Sung et al. 2010]. See also the Product Ecology by Forlizzi [2008] and Raptis et al. [2014], who describe various ecology concepts that have been proposed within HCI, such as the information ecology, artefact ecology, and personal ecology. Van Wynsberghe and Li [2019] propose a reframing of the HRI model from dyadic interaction to a model of human-robot-system interaction (HRSI). A dyadic interaction model does not account for all the effects of introducing a robot in a care context, such as impacts on the healthcare system as a whole. In the model they propose, the bot is viewed as a mediator between the healthcare system and the patient. In this case, the bot is seen as closely connected to the company that developed it (for data collection, data processing, and upgrades).

Finally, *sociality can be located across a network*. Law [1992] characterizes ANT as a sociological approach that describes humans, machines, objects, organizations, society, and alike, as heterogeneous networks or the effects produced by heterogeneous networks. Actors are themselves networks (which is why actor and network are coupled in the name actor-network): "*(...) a machine is also a heterogeneous network - a set of roles played by technical materials but also by such human components as operators, users and repair persons*." [Law 1992, p. 384]. The concept of punctualizations describes the phenomenon that complex heterogeneous networks are masked by simple actions and that which causes the action, which comes to stand in for the complex network. This is applicable to a complex system such as a robotic system that comprises, for example, various devices and a human operator, but what is perceived is simply the robot performing actions. ANT scholars suggested that there is no distinction between the social and the material. Socio-materiality indicates that what is material constitutes the social, and the social constitutes the material [Leonardi 2012]. Yaneva [2009] discusses the application of ANT to design, arguing that design can be viewed as a connector that shapes social interactions. How something is designed is directly tied to the particular way in which it mediates social relationships; the way something is designed shapes the social in a particular way. Vallès-Peris and Domènech [2021] propose "Caring in the In-Between", an approach toward responsible technological development of robotics and AI technologies in the care sector. The approach considers the robot as embedded in a network instead of as partaking in a dyadic HRI.

Alternatively, Verbeek [2008] describes technologies as not being neutral, and instead technologies serve a mediating role for human action, impacting human decision-making and configuring the conditions in which they can act and thus the conditions of their freedom. Verbeek distinguishes three forms of agency: human agency in the interaction with a technological artifact, the agency of the technology designer in shaping its mediating role, and the artifact's agency through the mediation.

These different views put the focus on developing different technologies. Contrast humanlike behavior for robots that relate to a human user in a humanlike social way to a view of social interaction as unpacking a designer's narratives in software (as in semiotic engineering), to a view of a robot impacting relationships within a family after its introduction to a household (e.g. Roomba [Sung et al. 2010]).

2.4. Design Spaces as Context-Specific

Harrison et al. [2007] state that the concept of design spaces fits the second paradigm or wave in HCI, as it suggests that there are aspects of design that can be varied without considering the context or how these aspects interrelate. A broader view of design spaces can be found with Botero et al. [2010], who write that the design space is not a pre-existing space, but instead, it is a co-constructed space formed by stakeholders, technologies, social processes. This moves the focus of the design activity away from the object, towards this broader context. This move towards including the context can and should also be made when discussing robotic systems, as "*(...) a system isn't complete without the people who use it*" [Smith 2006, p. xii] and the environment and situation it is embedded in. The concept of a design space should not be restricted to aspects that can be varied in isolation. Instead, it should be considered as situational and context-specific. Definitions of robots and robotic systems by the ISO focus on robots as programmable devices and associated sensors and other equipment [International Organization for Standardization (ISO) 2012]. However, in a design context, it makes sense to approach robots from a socio-technical systems perspective, as a system is designed for people. A broader approach can be found with the ISO definition of an interactive system, in which reference is made to hardware, software, associated services of the system, documentation, training, branding, and packaging [International Organization for Standardization (ISO) 2010]. One can go even further and include humans and their social worlds - and by extension, the natural environment.

Moving beyond a focus on individuals and their experiences, Frauenberger [2019] argues that the focus of design work should not be on designing better user experiences. Instead, designers should design for enabling "*meaningful relations*" within socio-material and socio-technical systems. Besides (or beyond) considering the impacts of technology on people, HCI should consider how humanity and its relationship to the world are reconfigured by technology design [Frauenberger 2019]. Johannessen and Perjons define a socio-technical system as "*a hybrid system that includes technical artefacts as well as humans and the laws, rules, and norms that govern their actions*" [2014, p. 12]. In order to design technical artifacts for socio-technical systems, a designer needs to recognize the knowledge present in such a socio-technical system and its individuals, practices and technologies. Though design as a discipline already moves beyond consideration of the technical artifact by itself, there is a need to consider effects on the situation and stakeholders involved, as well as larger societal implications. For social robotics, Šabanović similarly argues that it is important to ground robot design and the evaluation of robotic systems in "*real socio-technical ecologies inhabited by potential users*" [Šabanović 2010, p. 447], proposing the mutual shaping framework that acknowledges the mutual influence that robotics and society exert on each other.

To conclude, while the concept of the design space can be discussed in terms of aspects that can be varied, it is important to keep in mind that these aspects also have effects together, both on the interaction and at larger scales (e.g. organization, society). The design space of interactions between humans and robots can be approached in different ways, depending on the paradigmatic view of interaction that is subscribed to and where the interaction process is located *(sociality in, through, and with the artifact or across a network)*. Interaction can be approached in different ways (as control, or as social interaction) and at different scales or levels of impact, from clicking a button on a GUI to environmental effects from robotic e-waste. All these levels are more or less relevant depending on the focus and scope of the design problem. However, the existence of those levels should be kept in mind and the levels that are meant to be responded to should be specified. Interaction can be considered as actions using a UI, but this leaves many aspects of interaction unaccounted for. Although the concept of UX is broader, it still focuses on the experience of an individual user. Parallels can be drawn between a move from considering a design space as containing what can be observed locally in a specific interaction (e.g. in terms of actions on a UI) to a broader consideration of interaction as part of a socio-technical system, and the *waves of HCI*.

3 Activities, Methods, and Processes of Designers

3.1. Design Methods and Approaches in HRI

Several authors have studied and reflected on design practice in HRI (see also Section 1). Deng et al. [2018] note that three design disciplines are part of social robot design: interaction design, industrial design, and design of the animation of the robot. Baraka et al. [2019] distinguish three main design approaches in the context of social robot design, namely human-centered design, robot-centered design, and symbiotic approaches that take strengths and weaknesses of humans and robots into account to design for symbiosis. Alves-Oliveira et al. [2022] identify three types of design processes for social robot design. A linear process includes sequential steps, for example, hardware exploration followed by interaction design experiments, implementing expressive movement, interaction design, and then resolving conflicts in the design. An iterative robot development process involves continuous improvement of the system's design based on user and team feedback. Data-point-driven processes take insights, background knowledge, and experiences into account.

Design methods used in HRI listed by Lupetti et al. [2021] include animation studies, 3D modeling, sketching, brainstorming, and human-centered design methods such as interviews, questionnaires, participatory design methods, focus groups, observations, personas, and critical design. User involvement is important; Alves-Oliveira et al. [2022] write that if user needs are not met and designs are not sufficiently validated through user involvement, this runs the risk of applying stereotypes in the robot's design and experiencing pushback from end users and other stakeholders as a result. A process that involves users at different stages in the workflow can lead to a more holistic understanding. Such a process can involve multiple different methods, such as surveying, interviewing or observing target users.

3.2. Characterizing Design Research

Design research practice can be conceptualized in different ways. It can involve activities ranging from the design of specific instances and engaging in a design process, to the development of methods and generalization of knowledge derived from the design practice into theory in some form, while being informed by a design stance.

Design practice can be characterized as comprising several overlapping activities. Different conceptual levels on which designers operate can be discussed.

Fallman [2008] proposes a model for interaction design that depicts interaction design research as a triangle with *design practice*, *design studies* and *design exploration* at its corners. Interaction design activity is made up of combinations of activities from all three areas. Fallman describes *design practice* as *practicing design*, that is, developing products and prototypes in a design team informed by a specific design research question. *Design exploration* on the other hand, is directed toward searching for alternatives, criticizing the state of things, and taking aesthetics into account in interaction design research, which links the activity to practices in contemporary art. The aim of *design studies* is to develop a discourse or body of knowledge around design research and its results, aiming to generalize and understand [Fallman 2008]. The remainder of this section discusses literature on characterizing design practice in a way that corresponds to the set of overlapping activities discussed by Fallman, noting that many activities fit multiple domains.

3.2.1. Design Exploration

In contrast to design work that aims to meet certain functional, idealistic or market demands, design work can also be applied to ask questions rather than answer them. Designers can propose counternarratives, which may be one of the powerful things about design. Speculative design is not bound to market demands or aiming to serve a specific function besides the encouragement of societal debate. Critical design uses speculative design to critically question the status quo (e.g. preconceptions) regarding, for instance, the role of technologies such as robots in our life [Auger 2014]. This is one of the advantages that critical and speculative design offers; it enables stepping outside existing narratives and critically questioning them, and can be used to propose new narratives.

3.2.2. Design Studies

Zimmerman et al. [2010] characterize design theory as either *theory on design* (knowledge of design as an activity) or *theory for design* (knowledge developed to improve the design practice), whereas Research through Design (RtD) is "*a research approach that employs methods and processes from design practice as a legitimate method of inquiry*" [Zimmerman et al. 2010, p. 310]. Interest in RtD has increased as the focus has shifted in HCI from improving usability to designing for wicked problem situations.

3.2.3. Design Practice

In the HCI, design research and design science communities, multiple characterizations of practices of designers can be found. Different types of activities can be part of a designer's practice, and different ways of conceptualizing design work and its aims exist. Johansson-Sköldberg et al. [2013] describe different discourses on design, contrasting designerly thinking as found in the academic literature to the design thinking discourse within managerial discourse. They write that design thinking, in contrast to designerly thinking, equates creativity to the design practice (although there is more to the design practice), and that design thinking is viewed as a toolbox in a way that lacks context. Johansson-Sköldberg et al. [2013] distinguish five "sub-discourses" in the academic literature for designerly thinking and design, namely as "*creation of artefacts*" (Simon), as a "*reflexive practice*" (Schön), as a "*problem-solving activity*" for wicked problems (Buchanan, Rittel and Weber), as a "*way of reasoning/making sense of things*" (Lawson, Cross) and as "*creation of meaning*" (Krippendorff). These discourses have different epistemological origins [Johansson-Sköldberg et al. 2013, p. 124].

A dominant perspective is that of the problem-solving perspective on design, Johannesson and Perjons [2014] write that design research (and specifically design science) solves practical problems through the development of artifacts, that is, a system, method, model or otherwise that is intentionally developed towards an end. They write that many such problems are so-called "*wicked problems*". Rittel and Webber [1973] introduce the term wicked problems in relation to planning theory. For planning tasks it should be considered what would be the right thing rather than the most efficient thing to do. Planners encounter situations involving societal problems that are ill-defined, without a clear goal for the solution and unclarity if a solution that is found will actually solve the problem. Similarly, wicked problems in design thinking are characterized by Buchanan [1992] as problems that are ill-formulated, in an environment with multiple stakeholders, contradicting information and values, in which intervention can have unpredictable results. Dynamically changing requirements and conflicting, fragmentary knowledge can make such problems difficult to solve [Johannesson and Perjons 2014]. Buchanan writes that design as a discipline defies definition and that design does not have a specific subject matter, and rather, designers need to respond and relate to problems in the given circumstances, taking into account the views of stakeholders. The easily-forgotten process of making the product concrete in the wicked problem context is part of the domain of design, and the design process cannot be reduced to its final product alone [Buchanan 1992]. In Šabanović [2010]'s mutual shaping framework, social robot design is put forth as a wicked problem. Social robots are intended for applications in society, a problem context with increased uncertainty and complexity, which requires the design to be more adaptable and requires more ethical consideration. Šabanović [2010] argues that new methods are required for social robot design that incorporate social and technical facets.

Several authors discuss complexity as part of the design practice [Stolterman 2008; Goodman et al. 2011], in line with the "wicked problem" narrative. Goodman et al. [2011] describe interaction design as a complex discipline involving different activities and types of knowledge and skills such as empathy with end users, technology knowledge, and capability of judging aesthetics. They describe a specific type of knowledge in the design discipline that rests on interpretation and reflective practice, with inherent ambiguity. The design practice is context-specific; from this context complexity arises and is experienced by the designer [Goodman et al. 2011]. Stolterman [2008] contrasts complexity in design to complexity in science and argues that these forms of complexity should be understood as different. Design complexity (or richness) arises from the designer's subjective experience in response to information, requirements, and possibilities in the situation that is to be designed for. While in scientific practice it is possible to reduce problem complexity by reducing the scope of the problem, for instance by only looking at very specific aspects of it, design practice needs to approach a situation holistically, which means that design complexity cannot be reduced in a similar way [Stolterman 2008].

Parallels can be drawn between ways of working in a design research team that aims to gather knowledge and develop solutions to the practical problems of a particular community and transdisciplinary research projects. In meeting the demands of a complex problem situation, both involve drawing on the knowledge of several academic fields and of stakeholders outside academia. With transdisciplinarity, the aim is to "*provide contextualized answers to complex questions*" [Szostak et al. 2016, p. 7], often by working in teams with several academic disciplines as well as non-academic stakeholders. In contrast, multidisciplinarity (or pluridisciplinarity, polydisciplinarity) involves the juxtaposition of several separate disciplines in terms of their methods and knowledge, without integration of those perspectives or developing a shared understanding [Szostak et al. 2016]. Interdisciplinarity has been defined as "*communication and collaboration across academic disciplines*" [Jacobs and Frickel 2009, p. 44]. With interdisciplinarity, the aim is to answer questions shared by several disciplines, integrating knowledge, theories and methods from these disciplines to develop a better understanding. This requires integration in an interdisciplinary research team; the team members should develop understanding of the others' perspectives [Szostak et al. 2016]. Reflecting back on the HRI context, HRI design research can be conducted in a multi-, inter-, or transdisciplinary fashion. Baraka et al. [2019] note that social robot design employs methods and approaches from the research fields HCI, computer science, engineering and human factors. In an interview study with roboticists who worked at companies that manufactured social robots, Alves-Oliveira et al. [2022] describe that their interviewees all reported being part of interdisciplinary teams, including such disciplines as mechanical and electrical engineering, computer science, psychology, and the arts. Šabanović et al. [2007] write that social robots can function as "boundary objects" in the collaboration across disciplines, providing a common focus while also functioning as relevant research objects in individual disciplines. Blackwell [2015] argues that instead of thinking about HCI as a discipline, one might also frame the field as an *inter-discipline* or trading zone in which researchers work from an interdisciplinary standpoint, negotiating between and collaborating with different disciplines, instead of trying to consolidate it as a discipline by itself, spurring innovation rather than establishment of a body of knowledge. Blackwell describes HCI as practice-based, requiring collaboration and reflection. This can also be argued for design work in the field of HRI.

To summarize, design research can include activities such as theory development, design exploration and developing prototypes and systems in a design practice. Different perspectives on design practice exist, among which a problem-solving perspective is dominant. When design research is conducted with the aim to solve practical problems in a real-world context in a design team that draws on several sets of expertise from different disciplines, design practice can be characterized as operating in a transdisciplinary context to solve wicked problems. However, other characterizations of design work are possible, depending on the activities that are conducted and by whom the work is conducted.

4 Design Knowledge: From Ultimate Particulars to Global Knowledge Production

4.1. Ultimate Particulars vs. Global Knowledge Production

There is a tension between local, context-specific results from design work and the aim to derive knowledge from these results that generalizes across other situations or problem contexts. While produced artifacts can be studied as part of sciences, reasons Buchanan [1992], this is different from what happens in the design context; the easily forgotten process of making the product concrete in the "wicked problem" context is part of the domain of design, and the design process cannot be reduced to its final product alone. Design contributes localized, context-specific results, in the words of Buchanan: "...design is fundamentally concerned with the particular, *and there is no science of the particular*" [Buchanan 1992, p. 17]. Stolterman [2008] writes that design activity is aimed at creating (to enable) ultimate particulars, that is, each specific situation (system, organization, people, context) will result in a different outcome when a designed artifact is introduced, and the designer should consider the specifics of a particular use context, even if the designed artifact is the same. This is the direct consequence of designing for a specific socio-technical system as sketched before. Stolterman contrasts this with the aim of science, which is to "*formulate universal knowledge that explains the complexities of reality on a level removed from specifics and particulars*" [Stolterman 2008, p. 58] - which Stolterman notes is a crude description of scientific aims, nevertheless, this still serves to illustrate the contrast.

Design science, in contrast to localized design practices, is a field of research in which knowledge production through design is recognized as contributing to a global practice. Johannesson and Perjons [2014] write that results from design activities are at times relevant for a local practice only, whereas design science aims to produce results for a global practice (which effectively comprises multiple local practices and the research domain). They argue that for design results to become relevant to design science, research methods used must be rigorous, the resulting knowledge should relate to existing knowledge, and should be fed back into the community of researchers and practitioners whom this knowledge is relevant for. Stolterman [2008] warns against a design science approach to interactive system design as this may risk using methods that are not appropriate for design practice.

4.2. Intermediate-Level Knowledge

The concept of intermediate-level has been proposed to bridge/unify a field that has both local and global knowledge contributions, and everything in between. Lupetti et al. [2021] argue that current design work in HRI is usually restricted to design instances, but in order to build on findings in design research, researchers need to move beyond production of individual instances. They discuss design knowledge as resulting from a reflective practice (Research through Design); knowledge is produced by reflecting on the activity of designing or reflecting on resultant artifacts. They discuss the concept of intermediate-level knowledge, which occupies a territory between general theories and specific instances. They argue that this concept could be informative toward the development of a *HRI design epistemology*. The concept of intermediate-level knowledge is also part of interaction design and HCI discourse Höök and Löwgren [2012]. To count as academic knowledge contributions, contributions proposed as intermediate-level knowledge should fulfill the academic quality criteria of being contestable (contribution is not already generally accepted and can be questioned, which implies a certain novelty to the contribution), defensible (rigorously argued) and substantive (relevant and worth the time investment) [Höök and Löwgren 2012]. Examples of intermediate-level knowledge include design guidelines, design methods, design patterns, and strong concepts. A criticism of Research through Design, as identified in an interview study, is that knowledge development was only implicitly part of the process or took place after project completion, and poor documentation of RtD processes [Zimmerman et al. 2010]. Additionally, RtD was critiqued on grounds of the existence of a romanticized view of the design process and the "genius designer" by practitioners and researchers engaged in RtD. Such a view may hinder knowledge development that is "*systematic, rigorous and relevant*" [Zimmerman et al. 2010, p. 316]. Lupetti et al. [2021] argue that design knowledge could be represented and built upon better in HRI if researchers would clearly document and articulate motivations regarding engagements with design activities.

Frauenberger [2019] criticizes the concept of intermediate-level knowledge, as it postulates the existence of a spectrum ranging from universal theories to individual design instances, that is, from positivism to social constructivism, without a shared epistemological basis. Frauenberger further criticizes the concept of intermediary knowledge for implying a loss of contextualized knowledge while not being sufficiently well-formulated to serve as theory: by looking for patterns of successful designs that can inform future designs, the context-specificity of what made it successful in the original configuration is lost. Besides, Frauenberger argues that there may be value not in how the pattern was similar in different contexts and thereby abstracting, generalizing, and reducing this design situation, but rather in how "enactments" were different. Intermediate-level knowledge may risk criticisms of lack of rigor or disregarding context [Frauenberger 2019]. Zamfirescu-Pereira et al. [2021] argue regarding generalization of design findings from exploratory prototyping for human-robot interaction design that the understanding of similarities and differences in application contexts is more relevant than the replicability of results.

A different spectrum of theory in design research can be found with Zimmerman et al. [2010], who view research results through design as contributing to theory through exploration. Zimmerman et al. [2010] argue that RtD has contributed knowledge in the form of "nascent theory", which can be placed at the start of a spectrum of knowledge development, where the spectrum ranges from nascent theory (resulting from exploratory work) to mature theory. Forlizzi [2008] describes the product ecology framework as a form of nascent theory, for instance. This framing suggests a "spectrum" from exploratory to more substantive theory contributions. This differs from the concept of intermediate-level knowledge as described before.

The concept of intermediate-level knowledge can be connected to a design stance and normative aspects of design. For example, design principles indicate values when they argue for such things as transparent communication to end users. Such principles inform an attitude to design and express a certain worldview: a particular reading (that may change in the future) of what design should do and what design artifacts represent and mean. There is a risk that intermediate-level knowledge in the form of design guidelines, for instance, can be interpreted as prescriptive, but the designer is also responsible in considering if and how such guidelines apply to a particular context. Besides its use to inform specific designs, it can serve as way to document a particular design stance/normative orientation, which can be useful for learning (developing a design stance oneself) as well as studying design research. Regarding the concept of the design stance, Buchanan [1992] considers two levels on which designers work: on a general level and on the level of a *quasi-subject matter*. The *quasi-subject matter* is part of the problem and situation at hand, and consists of a set of issues that is not exactly defined in the (wicked) problem context. The designer responds to the quasi-subject matter with a specific product, thereby making the quasi-subject matter concrete. The general level is explicitly described as not being constitutive of any kind of science, rather, it informs a kind of design stance or a general view of designed artifacts, the methods and scope of the design practice.

5 Design Research as a Normative Activity

- "*In contrast to empirical research,design research is not content to just describe, explain, and predict. It also wants to change the world, to improve it, and to create new worlds. Design research does this by developing artefacts that can help people fulfil their needs, overcome their problems, and grasp new opportunities.*" [Johannesson and Perjons 2014, p. 1]
- "*Everyone designs who devises courses of action aimed at changing existing situations into preferred ones*" [Simon 2008, p. 111]
- "*In essence, design is about understanding the current state and then designing an improved future state*" Holmquist and Forlizzi [2014, p. 1]

To summarize, a strong narrative regarding design research practice is that design concerns itself with building future situations - identifying needs/problems in a current situation and developing systems and artifacts that alter the situation, with the aim to improve it. In a problem-solving view of a design practice, the aim to improve an existing situation is a value judgement on what a preferred condition would be. This improved future state that design research is said to strive for could entail an improved user experience, better living conditions, or empowerment of users, though we may also go beyond the idea of "serving user needs"; Frauenberger [2019] describes technology creation as a process in which humanity redefines itself. The aim of design is not "universal knowledge production" as a project in and for itself, as in science, abstracting reality while guaranteeing reproducibility and objectivity (see Stolterman [2008]'s description), from an observational standpoint. As established previously, design work is instead context-specific and calls on the subjective experience of the design team involved, as well as on others' subjective experience (e.g., that of stakeholders). Bartneck et al. write that designers (and engineers) aim to transform reality rather than understand it. Bartneck et al. consider the latter to be the aim of science [Bartneck 2020].

Transforming reality implies an *intentional stance*; designers have aims when designing artifacts and systems, such as supporting people in their work [Johannesson and Perjons 2014][2]. Buchanan writes: "*The history of design is not merely a history of objects. It is a history of the changing views of subject matter held by designers and the concrete objects conceived, planned, and produced as expressions of those views*." [Buchanan 1992, p. 19]. Technology developers have purposes for the work they do, whether such aims are explicitly stated, for instance, building efficient systems, or more implicit. Cheon and Su [2016] investigate narratives that indicated values in interviews with 27 roboticists. One of the motivations of roboticists they identified was to research (features of) humans such as human intelligence and language by developing humanoid robots. Šabanović argues that a designer's cultural assumptions impact robot design and identifies a technocentric mindset in which robots are viewed as "*technological fixes*" [2010, p. 439] (see also process dogma and the other oblique constraints for technology design identified by Auger et al. [2017]). Note that designers can also find themselves within an environment that produces a certain normative orientation. Rather than seeing robots as a technological fix, we should acknowledge that design comes with additional consequences. Technology opens up specific possibilities for action, potentially closing others.

Technologies mediate the way they are used; human action is directed, shaped, impacted by technology use. Verbeek [2008] posits that technological artifacts have a form of material morality. Technologies are not neutral; instead, they are "*active mediators that help shape the relation between people and reality. This mediation has two directions: one pragmatic, concerning action, and the other hermeneutic, concerning interpretation*" [Verbeek 2008, p. 94]. First,

2 In discussions of the three waves of HCI, questions have frequently been asked regarding what "good" means in relation to the third paradigm and what should be strived for in technology design. Fallman asks "what constitutes a good user experience" [Fallman 2011, p. 1053] and proposes taking philosophy of technology (especially Borgmann and Ihde) as a starting point to consider questions regarding what the vision of "good" may mean for third wave HCI. Similarly, Harrison et al. [2007] asks "what it means for a system to be 'good' in a particular context" [Harrison et al. 2007, p. 6].

this means that technologies influence and shape human action. Second, they bring awareness in the sense of offering the possibility for humans to interpret a given situation in a different way, and enable different choices than would be the case without said technologies (e.g. Verbeek gives the example of conducting an ultrasound and the possibilities for choice and action this opens up). Although the action of the artifact is not deliberate, it gives direction to human action. "*Technological mediation, therefore, can be seen as a specific, material form of intentionality.*" [Verbeek 2008, p. 95] What is noted is that the intentionality of the technological artifact cannot exist in isolation; rather, it arises from the combination of technological mediation with human decision-making (hybrid intentionality). Technological artifacts thus represent a kind of constitutive force for human action, implying that technological artifacts implicitly direct human action (thereby having a form of material intentionality) as well as configure (some of the) conditions for human freedom. Because technology configures material conditions and impacts people's decision-making and freedom, "*technology design is inherently a moral activity*" [Verbeek 2008, p. 99] and designers should concern themselves with the future roles of the technologies they are developing - even though it is difficult to predict how technologies will mediate human actions in different contexts.

The intentional stance of designers (and that of engineers, too) brings responsibility. Stolterman writes that "*research aimed at changing and improving "reality" always takes on responsibility in relation to whom or what it serves*" [Stolterman 2008, p. 63]. This responsibility is acknowledged in e.g. Value-Sensitive Design, which positions alignment with specific values to the forefront in a design process. For instance, the aim of Care Centered Value Sensitive Design (CCVSD) [Van Wynsberghe 2016] is to incorporate care ethics into care robot design. Fronemann et al. [2021] argue that for social robots, risks of loss of control and privacy should be investigated and argue that design solutions that address these risks can be found by combining UX design and ethics. The point remains that apart from integrating ethics/values into the design process, the aim of design work should be critically reflected upon.

As sketched in Section 2, it is important to consider designing for the socio-technical system. However, this discussion can be taken even further. Going beyond socio-technical systems, toward the socio-material conditions mentioned by Frauenberger, it is also necessary to give consideration to other biological species and the natural environment (as argued, for instance, in relation to AI ethics [Owe and Baum 2021]). Such a proposal towards seeing technology, society, and nature as entangled can also be found in *critical making*, which acknowledges the fundamental interconnection between nature and culture. As a society, we face social and environmental problems that need to be addressed in a way that acknowledges the hybridity of nature and culture, community values and Global

North-Global South relations. "*The stakes are (...) high - nothing less than the fate of our planet (...)*" [Ratto 2016, p. 28].

6 Conclusion

To revisit the line of argument followed in this chapter, it was argued that the socio-technical system that a robotic system is embedded in needs to be considered as part of the design space of interactions between humans and robots. The concept of interaction that is subscribed to merits consideration, as this informs the research questions that are asked, methods used, and solutions that will be proposed. Taking a view of design work as solving wicked problems, HRI designers operate in complex problem contexts, often requiring collaboration across academic and practical disciplines, in order to design/configure conditions for the socio-technical system that is the HRI design space. However, other approaches to the design practice are possible, for instance, design practice as reflection on or criticism of current situations.

We cannot conclude what "the design practice" "is", as it comprises many different activities, aims, and contexts, at different levels of detail. It is open-ended, transforming with the possibilities and demands of a specific situation and insights and design stance of designers who respond to this situation. From Fallman [2008]'s conceptualization of interaction design work and the complexity of inter- and transdisciplinary design work, we conclude that designers employ a variety of methods and (can and should) use multiple lenses within their "discipline". The different perspectives offered through a critical design approach, producing specific design instances in context, the implicit design stance that design professionals develop over the years, and design theory development can inform each other and function in complementary ways.

A tension exists between the "localized" knowledge contributions that design practices produce compared to global knowledge production in design science or design research. The concept of intermediary knowledge has been proposed by other authors to bridge those local and global results, but such a concept can be criticized if it depicts knowledge contributions as lying on a spectrum from specific to general knowledge contributions. However, what can be acknowledged is that there can be value in such knowledge contributions as documenting a particular design stance or interpretation of design instances.

Finally, it was argued that a designer's intentional stance is inherent to design work. Typically, the aim is to transform reality to a more desirable state (with what qualifies as desirable depending on those involved in the design process, for instance end users in participatory design), but other aims can include criticizing the current state (e.g., in critical design) or imagining a different state (e.g., speculative design). When HRI research is applied in practice, this makes the social responsibility on the part of HRI designers apparent. Designers also find themselves within an environment (e.g. institutions such as universities, corporate environments, academic discourse) that produces a certain normative orientation and introduces constraints. It remains important to reflect on one's social responsibility and how our institutions and discourses impact and reinforce normative orientations in relation to this responsibility.

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