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van Beek, E.

DOI
10.4233/uuid:179998fd-d779-4068-8101-f76fc3261a68

Publication date
2025

Document Version
Final published version

Citation (APA)
van Beek, E. (2025). *Designing with improvisations: How everyday practices with technologies shape sustainable transitions*. [Dissertation (TU Delft), Delft University of Technology]. https://doi.org/10.4233/uuid:179998fd-d779-4068-8101-f76fc3261a68

DESIGNING WITH IMPROVISATIONS

EVERT VAN BEEK

HOW EVERYDAY PRACTICES WITH TECHNOLOGIES SHAPE SUSTAINABLE TRANSITIONS

Designing with improvisations

How everyday practices with technologies shape sustainable transitions

Dissertation

for the purpose of obtaining the degree of doctor
at Delft University of Technology
by the authority of the Rector Magnificus, Prof.dr.ir. T.H.J.J. van der Hagen,
chair of the Board for Doctorates
to be defended publicly on
Wednesday, 18 June 2025 at 17:30 o'clock

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This work was supported by the Rijksdienst voor Ondernemend Nederland. This project is implemented with support from the MMIP 3&4 scheme of the Ministry of Economic Affairs & Climate Change and the Ministry of the Interior & Kingdom Relations.

ISBN: 978-94-6473-834-6

Book design:

Cover illustration	Jan Willem Hoftijzer
Cover and layout	Evert van Beek
Printed by	Ipskamp

An electronic copy of this dissertation is available at: https://repository.tudelft.nl/

If every novel object of design sets an obstacle in our path, and if to improvise is to chart a way through or around these obstacles, how can design for improvisation be anything other than a contradiction in terms?

– Tim Ingold (2016, p. 32). The Perception of the User–Producer. In W. Gunn & J. Donovan (Eds.), *Design and anthropology* (pp. 19–34). Routledge.

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Glossary

Conceptualization An abstract, simplified view of some domain that we wish to represent for some purpose (B. Smith, 2003).

Everyday practices The routine, mundane activities that constitute daily (domestic) life, such as cooking, heating and laundering (Kuijer et al., 2013). Practices are socially shared, recognizable and performed by many people in a society. Practices, considered holistically, include the knowledge, meanings, routines, and material components involved in these activities.

Transitions Transformations of society with changes on institutional, social and cultural, organizational, and technological dimensions (Loorbach et al., 2017). Many ongoing transitions revolve around sustainability, energy systems, and mobility. The *heat pump* transition in the Netherlands is one case of an ongoing transition.

Technologies in transitions Technologies are part of broader socio-technical systems providing services to (members of) societies. *Technologies in transitions* are those that are introduced-, or need to change-, as part of transitions. Examples in ongoing transitions are solar panels, electric cars, energy storage systems, and heat pumps. The supply side of a technology develops and sells these technologies as products to resellers, installers and consumers. Together these form a value chain.

Heat pumps Heat pumps, in this context, are devices (*technologies)* that transfer heat from outdoor air-, ground- or water-sources, to a place where heat is needed, such as for heating indoor spaces or domestic hot water. Heat pumps are also capable of cooling a building. In the Netherlands, heat pumps replace less sustainable residential heating systems, such as gas boilers which run on fossil fuels and directly or indirectly lead to more CO2 emissions. In some cases, I will refer to indoor climate technologies in general as heat pumps.

Appropriate practice A variety of *everyday practice,* fitting to the context in which it is performed.
For humans performing the *practice*: What people in the context of their performance of that practice, consider or judge as 'normal' and/or fitting to the situation at hand.
For technologies performing the *practice*: What technology designers considered normal or desirable during the

	design phase, in relation to predetermined goals, such as saving energy.
Practice reconfigurations	Changes to (performances of) *everyday practices*. These can be reconfigurations of knowledge, materials, or routines (chapter 3).
Co-performance	(The idea of) practices being performed by both humans and (automated) *technologies* (Kuijer & Giaccardi, 2018).
Crises of routines	When performers (temporarily) do not know how to go on with a *practice* (for example, when a necessary material element is missing, or because a technology acted in a way that humans did not find appropriate or fitting with the situation at hand. (Reckwitz, 2002))
Conflicts	When ideas of *appropriate practice* differ between those performing the practice (humans and technologies). *Conflicts* might not become apparent, but when they do, they lead to *crises of routines* (chapter 2).
Everyday improvisations	Everyday improvisations are changes in everyday practices with technologies in societal transitions. They are improvised resolutions of *crises of routines*. Human performers figure out a way to continue everyday life, creatively and on the spot (chapter 2).
Response	An intervention, activity, or change to activities (of designers or value chain actors) in reaction to improvisation (chapter 4).
Enacted interface	A persistent matching of human and technology (a particular kind of practice reconfiguration). A new, improvised 'solution to the problem of matching people to things' (chapter 2).
Sites of intervention	Specific locations or aspects within a (socio-technical) system where targeted design activities create opportunities for change (chapter 4).

1 INTRODUCTION

In this chapter, I outline the context and background of this research. I articulate the need for a conceptualization of everyday practices with sustainable technologies in transition. I explain how such a conceptualization might benefit the fields of design research, and other fields of knowledge concerned with transitions and technologies. I state research objectives and research questions and provide an outline of the dissertation.

It is the spring of 2021, and in one of the earliest research activities of this PhD, I visit Emma[1]*. My goal is to find out what the Dutch energy transition looks like 'on the ground', in households. Together with her two large snow-white cats, Emma lives in a social housing apartment in the South West of the Netherlands that was renovated to all-electric and net zero energy in early 2018. Equipped with a video camera, I introduce myself as a researcher from TU Delft trying to understand how the heat pump in her recently renovated zero-energy-rated apartment impacts her life. Emma tells me she will not be an interesting case for our research, because she keeps the thermostat always on a low setting and barely touches it. She is happy with lower temperatures, and keeps the door open when she smokes on the balcony, so heating would be a waste anyway. She goes on to show me some of the buttons and displays located in various parts of the house that all connect to the heat pump, but she has to search as she rarely engages with any of them. When we come to a display located in a cupboard in the hallway, Emma requests my technical expertise, and asks me for some explanations. I find it hard to interpret what is on the display. In fact, I find it hard to understand how Emma manages to influence the temperature in her apartment at all. Emma seems disinterested in understanding the technical functioning of her heat pump, or what it is doing to the indoor temperature. It turns on and off without her doing. How would this technology help her save energy? And: What will I be able to learn from this visit?*

Coming back to the living room, our conversation turns away from technical matters, and Emma starts talking about the care for her cats, and how one of them is quickly getting older. She then explains how this cat enjoys the new heat convector units in the living room. In summer, he enjoys the slight breeze of the fans cooling the room, while in winter the convector adds some more warmth to the sunny spot in the window. While Emma can barely feel whether the heating is on, and also cannot tell from the displays, she has some information about heating which she makes use of. She will not open the windows whenever the cat enjoys the convector, as this would surely sacrifice some of the heat for the cats. Recently she has installed sun blocking curtains, which again she is careful to open only whenever the cat needs. The heat pump meanwhile does its job, rarely turning on, following the low thermostat setting. Before entering this apartment, I had heard that the heat pump manufacturer collects energy consumption and indoor climate sensor data from this and other households. In this dataset, Emma must look like someone showing exemplary energy conserving behavior. From the numbers, this household appears very motivated to save energy and live sustainably, but from what Emma showed and told me, sustainability plays only a marginal role in her practices.

[1] Like in all ethnographic vignettes in this dissertation, the names are pseudonyms.

Figure 1.1. A video still showing how I am just too early to capture the moment Emma's cat takes a leap to the top of the convector.

Emma's story[2] can be studied as a case of poor human-centered interface design. Indeed, the displays she was tasked to interact with gave Emma little control over and understanding of her heat pump or climate regulation system. But this dissertation is not about user friendly design. Instead, in light of this dissertation's argument, the vignette above highlights *everyday improvisations*. The events recalled in the vignette are an example of how technologies and residents perform everyday practices together and next to each other. I refer to this as *co-performance*[3]. These performances do not always go smoothly. When a new technology, such as the heat pump, enters the household, it disturbs existing everyday practices. Something needs to change about how people (and technologies) go about their day. This might be described as a *crisis of routines*. Times of change in households, impelled by *sustainable transitions*, reveal that humans and technologies take part in everyday practices according to different ideas of what is appropriate. And these ideas are not always aligned. In the described case, technologies are designed to realize ideals of sustainable societal transitions by saving energy, while Emma is interested in caring for her cats. In other words, there is a disagreement, or an underlying *conflict*, between technology designers (and by extension the technologies themselves) and people performing everyday life together with these technologies. The vignette does not stop here though. Emma, together with her cats (figure 1.1.), figures out a way to manage her indoor climate and continue everyday life. This figuring out in everyday practices, in response to challenges presented by technologies, is what I call *everyday improvisations*. These everyday improvisations are what I am particularly interested in, and give this dissertation its title. I approach these everyday improvisations in transitions from

[2] Initially reported in a paper for the Clima 2022 conference (van Beek & Boess, 2022)
[3] A glossary of key terms adopted, used and developed in this dissertation, can be found before chapter 1.

a design perspective to explore the relationship between everyday life and technologies, with the aim of contributing to the discipline of design research. This results in a conceptualization of changes in everyday practices with technologies in societal transitions. These changes are conceptualized as improvisations. Adopting the conceptualization developed in this dissertation, implies that design practices in ongoing sustainable transitions do not ignore these everyday improvisations or take them for granted. Instead, everyday improvisations have the potential to contribute to the goals of transitions, if they are recognized as valuable. This dissertation is thus about the relationship between everyday practices, technologies, and societies in transition, and about what design has to offer in this relationship.

1.1. The problem of design in transitions

Design does not have one past, but many potential pasts (Göransdotter, 2020). One of the histories that is most dominant now, is that of an expanding toolbox for solving increasingly complex problems. For a long time, those problems have been the problems of individuals. The most dominant approach in design, human-centered design (HCD), advocates for understanding and solving the smaller and bigger problems that technology users encounter in everyday life.

The challenges faced by society today demand ways of thinking and designing that go beyond individual user problems. Climate change in particular presents uncertainty and radical societal change. Dealing with these challenges requires sustainable transitions: a restructuring of societal systems involving a broad range of actors and stakeholders, and a change to our practices and ways of living (Gaziulusoy & Brezet, 2015). Here, the practice of design has an ambiguous image. Its (historic) role in the mass production of objects and technologies that enable resource consumption contravenes efforts to achieve sustainability as a society, and is increasingly seen as part of the problem[4] (Spangenberg et al., 2010). Meanwhile, design is also called upon to contribute to sustainable transitions (Gaziulusoy & Öztekin, 2019)[5] and more sustainable technologies are seen as critical to realize sustainable change (Kemp, 1994). But the challenge of realizing sustainable change with technologies is of a different order than the usability and practical problems that designers often address. Not only is there a different set of stakeholders involved, but there is also a different mode by which these technologies are taken up in everyday practice. Transitions involve changes to everyday life, and technologies are part of these changes.

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[4] Design being implicated in the political and economic systems in which it operates.

[5] One response to this call is the development of the field of transitions design. Transition design aims to utilize design as a catalyst for change towards sustainably futures (Irwin, 2015). It does so by fostering systemic change. By focusing on systems, transition design is necessarily agnostic about the specific technologies that might contribute to transitions. The focus is on social functions within systems and any type of designed intervention (physical or non-physical) might contribute to bringing about system change (Gaziulusoy & Brezet, 2015). This dissertation does not squarely belong to the field of transition design. Instead, I take a different point of departure: a particular technology that features in an ongoing transition.

Design in relation to these technologies is no longer only about solving user problems, but also about societal goals and how they are realized in this changing everyday life.

In what follows I[6] will attempt to unpack this problem of the role of design in transitions, by tracing the connections between technologies in transitions, and traditions of technology design, with a particular focus on everyday practices.

1.2. Technologies in transitions

As Western societies slowly wake up to the reality of climate change, transitions are set in motion. It is increasingly acknowledged that, in order to achieve some form of sustainability and work towards climate justice, there is a need for a transformation of society. Societies need to change on institutional, social and cultural, organizational, and on technological dimensions (Loorbach et al., 2017). These dimensions are closely interwoven and require each other. Technology will not act as a silver bullet in achieving sustainability (Alexander, 2014). In other words, systems need to be considered holistically. Still, in this dissertation I want to take a starting point in a particular technology and the way it might contribute to lower consumption of resources as a society.

Examples of technologies in ongoing transitions in the Global North are solar panels, electric cars, energy storage systems, and also include heat pumps, which provide the case for this dissertation. These technologies fulfill a specific function in everyday life and its relation to energy. They turn energy into a service (in the case of electric cars and heat pumps), they produce energy locally (like solar panels), or they contribute to a stable energy supply (like with energy storage).

However, technologies in transitions are not primarily developed to solve a problem for individual people in everyday life. Instead, their defining feature in the context of transitions is that they address collective 'other-than-individual' human concerns which transcend everyday life. They are developed to save or produce energy, to contribute to grid balancing, to aid national energy independence, or even to be catalysts of more widespread change towards climate justice.

Technologies in transitions are thus not primarily developed for offering benefits to end-users by solving problems in everyday life. Instead, they are sold and 'diffused' through society based on other dimensions. To name just a few: These technologies appeal to monetary benefits, often with the help of subsidies. They might also speak to other values, such as an individual's interest

[6] In this introduction and in the discussion, I write in first person singular ('I') reflecting single authorship, while the chapters 2-5 are written in first person plural ('we') reflecting the contributions of multiple authors.

in supporting collective sustainability. Sometimes, these technologies become the only available option (for example, because an employer only leases electric cars).

However, by focusing on other dimensions, it is easy to overlook the dimension of everyday practices. Technologies in transitions are often notably different from their predecessors in the way they participate in everyday life. These changes are unique to each technology and the situation in which they are encountered. Electric cars, for example, will require longer and more frequent stops on long road trips, compared to combustion engine cars. Solar panels make it attractive to use the washing machine at specific times of the day. Inevitably, these changes require end users some 'getting used to'. In short: technologies in transitions impact everyday practice (in ways that will be explored in much more detail in this dissertation), without being primarily designed for this impact.

At this point, it seems attractive to turn to design as a field that is experienced in pragmatically positioning and formatively exploring the relation between everyday life and technologies (Shove et al., 2007). In taking such a turn, one could follow several lines of argument, which result in different entry points in design. I take as a starting point the most enduring, and most institutionalized (in e.g., ISO 9241-210, 2019) exponent of design traditions: human-centered design.

1.3. Human-centered design of technologies

Technologies solve problems and extend the capabilities of the human organism. This is an idea that is encountered regularly in thought about technology, design and the relation of the human to the natural world (Brey, 2000). Such a conceptualization sets the stage for a particular way of approaching the design of those technologies[7]. In this view, design starts (historically, rhetorically, and as a process) with the human, often thought of as the user of the technology[8]. Designers, caught up in company dynamics of engineering, manufacturing and marketing might easily forget this starting point, which is why there is a need for a human-centered design. The

[7] From here on, I will use the word design to refer to design of, or in relation to, technologies. This is a strategic choice in the context of this dissertation for a particular narrative and tradition (shared with others such as Pineda et al., 2024). It is motivated by the focus on technologies as a starting point, and fits with a dissertation that also engages with engineering disciplines. One could very well have a much broader understanding of the discipline and theory of design. In such a broad definition, design has other objects than technologies, such as visual material, buildings, or furniture. Such histories of design will often start with the Bauhaus as the place where thinking about design took off (e.g., Giaccardi & Redström, 2020; c.f. Göransdotter, 2020; Redström, 2006).

[8] Whether that human is conceptualized as a user interested in functionality and needs only (as in user-centered design), or considered more holistically to include emotional, aesthetic, or even social aspects (relabeling the approach to human-centered design) is not the focus here. In the text of this dissertation, I will use the term human-centered design as a blanket term to also capture what is formally named 'user-centered design'.

approach of human-centered design has a particular genealogy that fits this narrative. Its origins lie in the engineering of machines and computers. Donald Norman is human-centered design's best-known advocate and greatly contributed to the development of the approach since the 80s. In his seminal work (2013), he often explicitly addresses his previous self as an engineer, focused on technical requirements and 'quite ignorant of people' (2013, p. 7). Engineers, supposedly, overlook the people for whom they design, being focused too much on the technology. A better design approach, Norman proposed, is to center the human in the design process. Methods from other disciplines such as psychology and anthropology can help designers understand better what people want and create a 'tight fit between object and user' (Redström, 2006, p. 124)

From such a view (and such a genealogy) follows a clear stance on everyday practices. Human-centered design is 'an approach that puts human needs, capabilities, and behavior first, then designs to accommodate those needs, capabilities, and ways of behaving' (2013, p. 8). Such an approach includes user involvement in design, empirical measurement and iterative design (Norman, 2013). In other words, it is imperative to study closely how people go about their day and achieve their goals, in order to design technology that fits with these everyday practices[9].

How does this human-centered design relate to technologies in transitions? One could argue[10] that human-centered design has much to contribute to sustainability. In this line of argument, technologies that are more efficient with energy, such as electric cars or energy storage interfaces, need to be designed according to the principles of human-centered design. Engaging with HCD is seen as a useful alliance, because it can reduce friction in use, which leads to more user and societal acceptance of these technologies, which ultimately leads to more of these technologies being implemented, reducing environmental impact in the long run.

There are important nuances and limitations to this argument, and subsequently to the argument for taking a human-centered design approach as the (only) approach to the design of technologies in sustainable transitions. In what follows, I will describe some of these limitations[11], which will ultimately introduce the problem addressed in this dissertation.

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[9] Of course, the design and research that happens under the label of human-centered design is not reducible to this simplified conceptual view. There are nuances, internal critiques and alternative approaches which are also associated with human-centered design (such as activity theory (Kuutti, 1996) and ethnographically oriented work (L. Suchman et al., 2002), and, of course, practice theory (Kuijer & Jong, 2011))

[10] And it has been argued to a certain extent (e.g., Agee et al., 2021; Bao et al., 2020; Rossi & Attaianese, 2023; Sellers & Fiore, 2013)

[11] There are other limitations that are of a more practical nature, relating to HCD's methods of e.g., consulting end-users (Velsen et al., 2022). Other challenges are introduced by digital technologies that participate in design processes (Giaccardi & Redström, 2020). As will become clear, many of these also apply in the context of sustainable transitions. Here, I focus on the ones that are about the fundamentals of HCD and transitions.

1.4. Friction or fitting in?

As I have argued in this introduction, transitions and human-centered design contain opposed ideas about everyday practices. As part of transitions, everyday practices *need to change* to align them with *other-than-individual-human concerns*. Human-centered design on the other hand is about *accommodating* to existing everyday practices and satisfying *individual-human concerns*. On a practical level, this raises a question for design: should technologies in transitions aim to change everyday practices, possibly by introducing some friction between existing practices and technologies? Or should design aim to fit technologies to the status quo of present everyday practices, and make energy consumption easy to the user? Can these two options co-exist? Does it depend on the specific technology or the situation? The answers to these questions depend on how one thinks about everyday practices and the ways and extent to which they interact with technologies, especially when technologies change.

To illustrate the relevance of how one conceptualizes everyday practices, it is helpful to look at some concrete phenomena emerging in technologies and everyday practice in transitions. Discussing these phenomena also brings some nuance to the provocative opposition of friction and fitting in.

1.4.1. Rebound effects indicate that everyday practices are not static.

Rebound effects refer to situations where more energy efficient technologies result in less energy savings than expected and sometimes higher, instead of lower, net energy use (Halvorsen et al., 2016). There is a wealth of evidence of rebound effects when technologies are introduced and diffused in societies. Several explanations are being explored to explain this rebound effect. It is well-known that, on a societal level, technological progress leads to increased standards of comfort (Herring & Roy, 2007). People travel further, now that air travel is available. Another, related explanation for the rebound effect focuses on the micro-level and argues that monetary savings, resulting from a more efficient provision of a good or service, are spent on consuming more of that service (Murray, 2013). People save money with more energy efficient car engines, so they travel further with them. Introduction of more energy efficient technologies thus results in unanticipated behavioral changes that reduce or eliminate the expected energy savings.

Rebound effects put the spotlight on the dynamics of everyday practices with technologies. The key takeaway from this phenomenon is that energy efficient technologies do not simply accommodate existing practices, even when they are designed to fit in with those practices. Instead, through complex and barely understood mechanisms, technologies change everyday practices. In other words, everyday practices with technology cannot be understood as static, as this runs the risk of unintentionally increasing energy use by supporting energy-intensive practices.

1.4.2. *User innovations highlight that friction between users and technologies might be productive*

Technologies in transitions are often new innovations. They are developed to address a problem that is emerging in a specific context (e.g., energy dependencies). These situations are dynamic, and a one-size-fits-all solution is often not available immediately. Instead, technologies need to be adapted to local situations. In these situations, innovations do not only emerge out of formal R&D departments or system development practices. End-users are also known to innovate (Hyysalo et al., 2017). For example, grassroots communities played a critical role in developing wind turbines in Denmark and end-users made solar collectors work for the local climate in Austria (Ornetzeder & Rohracher, 2013). End-users are hacking, developing and 'locally reinventing' (Jalas et al., 2017) technologies, to appropriate them and optimize their performance in everyday life. These innovations are then shared through internet forums with peers or sometimes commercialized by end-users becoming entrepreneurs (Hyysalo et al., 2017).

User innovations highlight that everyday practices change when technologies are introduced in these practices. But these changes to everyday practices contain sparks of creativity and potential innovations. The friction that emerges when new technologies are introduced could lead to positive outcomes in terms of (technical) innovations leading to lower energy use. Everyday practices with technologies in transitions can thus not be understood as frictionless, as such a view might easily miss out on productive outcomes of friction, such as user innovations.

1.4.3. *Technologies that automate everyday practices remove human judgment from everyday performances*

Technologies introduced in transitions often involve a degree of automation, reducing human intervention in processes. The expectation is that automation can contribute to reduced energy consumption and the use of energy at the right time. Electric car charging, for example, leads to peak loads on energy networks when commuters arrive home in the evening, even though a charged car is only needed in the morning. Automating this process might mean that charging the car happens at optimized times, such as in the middle of the night. Here, automation of energy consumption is expected to address these peaks and contribute to reduced energy consumption by doing the tasks that people used to do in a more efficient or 'smart' way (Norouzi et al., 2023; Strengers, 2014). The idea is that smart metering, smart grids, home and vehicle charging automation, provide users control of when, how and where devices demand electricity, whilst maintaining service levels to households in terms of lighting, warmth, power and mobility (A. Smith et al., 2023). However, such automations also imply that decisions about energy consumption (about when to heat, when to turn the light on or off, and when mobility might be needed), are no longer solely made by end-users (with a flick of the light-switch), but delegated in part to technologies and their developers. This creates situations where automated lights are turned on, even when no one is home, just because the automation runs in the background.

The automating features of technologies in transitions highlight that everyday practices cannot be understood as performed by humans only. Such a view runs the risk of selling technologies, but continuing or even intensifying energy intensive practices, now just performed by technologies rather than humans, which might further contribute to rebound effects (Kuijer & Giaccardi, 2018). Ignoring the participation of technologies in practices also overlooks the ethical (and political) dimension of frictions that emerge in everyday practices when technologies take decisions according to technology developers' ideas of appropriate practice, rather than those of end-users (Strengers, 2014).

1.5. A problem across multiple domains and a design perspective

As I introduced above, everyday practices are relevant to technologies in transitions. These everyday practices are studied across many different *domains* of knowledge and *disciplines*[12]. For example, researchers could focus on the societal level, they could discuss specific technology features, or focus on energy consumption numbers; all of which produce valuable knowledge about everyday practices with technologies in transitions. The phenomenon of everyday practices with technologies in transitions, as it is emerging from the description above, has at least two facets, which are also relevant to design.

One facet of everyday practices is that practices change and interact on a societal level. Knowledge about this can be found in the *domain* of societal change and transitions, investigated primarily by the social science *disciplines*, such as sociology and innovation sciences, which produce implications and recommendations primarily for policy (van den Bergh et al., 2021). In this domain, one key question related to the phenomenon of everyday practices with technologies in transitions is how the micro-level of practices interacts with macro-level socio-technical, societal, and systems change. Technologies and innovations clearly play a role in this interaction. However, what exactly their relation is, remains contested (Keller et al., 2022), while recommendations for practice and other prescriptive knowledge are scarce (Wiegmann et al., 2023).

Another facet of the phenomenon of everyday practices with technologies in transitions, is technological. It connects to knowledge about how these technologies are developed, marketed and implemented, and their energy consumption or production in use. This knowledge is typically organized in specialized, technology related *domains*[13], such as solar energy or transportation research. *Disciplines* that study these specialized domains also tend to be more technical and focused on physical properties or engineering design and analysis. For these domains, open questions related to everyday practices with technologies in transitions concern choosing the right technical solution, while making sure that projected energy savings are

[12] Here, I do not use the word *field*, but instead make a difference between domains and disciplines. Following definitions from information and knowledge sciences, I define a *domain* as the knowledge organized around a problem or subject that researchers from many disciplines might work on, while I regard a *discipline* as a field defined by research methods, publication outlets, academic conferences, and associations (Hammarfelt, 2019; Hjørland, 2001).

[13] Although there are also broader research communities reflected in the contributions to, for example, the *Journal of Cleaner Production*.

reached. Everyday practices introduce uncertainties in these domains as they have impact on energy use, but cannot be determined and predicted like the technical properties of these technologies. (This problem is further unpacked in the case description under §1.8.).

Current practices and emerging research indicate opportunities for bringing design research to these two (types of) domains: transitions research (e.g., Wiegmann et al., 2023) and specialized technical domains (e.g., Pettersen, 2015). A design perspective might complement existing research and contribute knowledge that addresses the questions highlighted in the previous paragraph. For the purposes of the argument here, I define a design perspective as a way to generatively explore the relation between everyday life and technologies. This definition is inspired by work such as that of Hult et al. (2006) who describe design perspectives on seven dimensions (*user, artifact, context, activities, communication, central relations,* and *use qualities*) (2006). The key point is that taking a design perspective highlights dimensions and relations of situations and problems, which might be overlooked by other disciplines. A design perspective might, for example, be informative in understanding how practices change in unintended ways when technologies are introduced (e.g., Wakkary & Maestri, 2008) (addressing open issues in transitions research) or contribute to an understanding of the way users might be involved in technology development to mitigate uncertainties about energy consumption (e.g., Bosserez et al., 2018) (addressing questions in specialized technical fields). As such, there are unexplored opportunities for design research to do interdisciplinary work in the 'borderlands' of disciplines and domains (Carter, 2011), and in this way connect different domains by bringing its own perspective, bridging situated problems and generic directions for solutions[14].

1.6. Emerging more-than-human-centered design approaches

Looking to flesh out such a design perspective, one encounters several emerging concepts in design academic literature that look at the dynamics of everyday practices with technologies. In this section, I very briefly review a selection of existing literature in design research. Starting from theories of practice, I look at how design approaches have conceived of the role of technologies in everyday practices. Without being formally designated in this way, these approaches are all *more-than-human-centered* design approaches, in the sense that they present a different view towards everyday practices than espoused in human-centered design. Until now, none of these approaches have been explicitly adapted to the dynamics of societal transitions, and the role of technologies within these transitions.

1.6.1. Theories of practice

Many studies looking at the introduction of new technologies in the household draw on theories of practice, for example the works of Schatzki (2019), Shove (2012) and Reckwitz (2002). In

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[14] In Newell et al.'s list of seven possible motivations for interdisciplinary studies (2001, p. 5), this research falls squarely into the third: *social, economic, and technological problem solving* (c.f. Boess & Kanis, 2008)

practice theory, society is viewed as a collection of practices and all human action as the performance of one or more practices. Theories of practice have also found some traction in the field of design and design research (Ingram et al., 2007; Kuijer, 2018; Pettersen, 2015; Shove et al., 2007) and the adjacent field of human-computer interaction (HCI) (Kuijer & Giaccardi, 2018; Pierce et al., 2013). This adaptation of practice theory to design has been loosely grouped under the title *practice-oriented design research* (Jalas et al., 2017; Pettersen, 2015). In this stream of design research, the practice theoretical framework is adapted to study everyday practices in detail and discover ways to influence these practices through design processes and designed interventions. Practice theory pays explicit attention to the situatedness and history of practices. Any new practice or change in practices has its roots in existing practices which are newly linked or reconfigured (Kuijer, 2014). These theories also emphasize that material arrangements (such as new technologies) reconfigure practical understandings, meanings, and conventions, and thus influence how practices are performed (Shove & Walker, 2010).

1.6.2. Creativity in use

Practice-oriented design research assumes that individuals practicing everyday life are creative in their adaptation to new situations (Shove et al., 2007). This makes designers collaborators in redesigning everyday practices, rather than the only authors of new solutions (Botero & Hyysalo, 2013; Scott et al., 2012).

Design literature has also discussed this creativity emerging in everyday life. An early term for this is *adhocism* (Jencks & Silver, 2013) which describes the use of arbitrary objects in an improvised way. *Design-in-use* (Botero et al., 2010; Henderson & Kyng, 1995; Nelson et al., 2009) and *everyday design* (Wakkary & Maestri, 2008) are terms used to describe how users take over existing products according to their own needs and practices beyond product design (using a chair as a step). *Non-intentional design* or *design by use* describes the more spontaneous changes people make to their environment in response to a problem (using a key to open an envelope) (Brandes et al., 2013a). Finally, *resourcefulness* is identified as a dispersed practice in which means are adjusted to purpose, and purpose to means in response to everyday 'crises of routines' (washing sports gear in the bathtub) (Kuijer et al., 2017). These can all be considered forms of *active design engagement* which has both individual and collective modes of expression (Kohtala et al., 2020).

Design research has introduced frameworks that connect this everyday creativity by end-users to more formal design work before the use phase. Examples of these are frameworks such as *meta-design* (Fischer et al., 2004a; Giaccardi, 2005), *open design spaces* (Budweg et al., 2010) and *end-user development* (Tetteroo & Markopoulos, 2015). These frameworks promote the idea of 'underdesign', where designers design open-ended systems that allow end-users to adapt technologies to their own purposes and situated needs.

1.6.3. More-than-human design

Meanwhile, design also engages with theories, concepts and insights that explicitly aim to move beyond human-centered design. The general point of these new approaches is that humans, nonhumans, and the environment can only be understood in relation to each other. This includes understandings of humans and technology which emphasize relationality, technological agency and assemblages composed of humans and non-humans (Giaccardi & Redström, 2020). Originating from, for example, feminist theories and science and technology studies (Forlano, 2017), these more-than-human notions increasingly find traction within HCI (Coskun et al., 2022). They offer theoretical foundations (Frauenberger, 2019), new considerations (Coulton & Lindley, 2019), ways of knowing (Wakkary, 2020), and even new roles for designers (Yoo et al., 2023). However, at this moment, these more-than-human design considerations have not materialized in concrete design practices (Nicenboim et al., 2024).

1.6.4. Co-performance

The concept of co-performance brings several of the aspects emerging from this brief literature review together. Co-performance extends the practice theoretical framework to include the participation of technologies in practices (Kuijer, 2019; Kuijer & Giaccardi, 2018). Following practice theory, the framework of co-performance considers everyday practice as a dynamic location where change takes place (Kuijer, 2014). Co-performance recognizes the doings (or performances) of automated technologies as part of these practices. These technologies participate in practices, not just as material elements but as performers that take on tasks (such as regulating indoor temperature or observing the weather) previously or also performed by humans. This implies that it is not just the human performer who can make a change in practices: agency is located in the *relation* of human and technological performances. Concretely, when one or both performs their part of the practice differently, this can be the beginning of a change in practice.

The framework of co-performance thus has a conceptualization of the dynamics of practices in relation to technologies, especially when these technologies or their roles change. Until now, this concept of co-performance has not been connected or extended to consider the dynamics of societal transitions, and technologies that are implemented as part of these transitions.

1.7. Knowledge gap: conceptualization of everyday practices with technologies in transitions

This introduction has identified the challenge of designing for everyday practices with technologies in transitions. I have identified how sustainable societal transitions and existing dominant approaches in design address concerns on different levels, the individual and the societal. This leads to two opposing stances towards everyday practices. In a human-centered design approach, which addresses individual user concerns, technologies are designed to fit in with existing everyday practices. Transitions, on the other hand, address other-than-individual-human concerns and are about changes to everyday practices.

I have also highlighted how the way that designers address this challenge, and design in the context of transitions, depends on the way that everyday practices with technologies are conceptualized. There are emerging more-than-human-centered design approaches that consider everyday practices with technology in ways that highlight the dynamics and inventiveness of everyday practices, and position technologies in an active role within those everyday practices. Until now, these approaches and understandings have not been applied to the context of sustainable transitions. There is currently no coherent *conceptualization* of everyday practices with technologies in transitions that can benefit designers working in this space.

Here it is important to clarify what a conceptualization is. A conceptualization is a particular view of the world that is appropriate to certain practices. In the words of information scientist Smith: *"As we engage with the world from day to day we participate in rituals and we tell stories. (…) We buy insurance, negotiate traffic, invest in bond derivatives, make supplications to the gods of our ancestors. Each of these ways of behaving involves, we can say, a certain conceptualization. What this means is that it involves a system of concepts in terms of which the corresponding universe of discourse is divided up into objects, processes and relations in different sorts of ways. Thus in a religious ritual setting we might use concepts such as salvation and purification; in a scientific setting we might use concepts such as virus and nitrous oxide; in a story-telling setting we might use concepts such as: leprechaun and dragon."* (2003). For the purposes of this dissertation, a conceptualization is defined as an abstract, or simplified view by which designers or others understand the world or a specific part of it[15]. It informs ideas and beliefs, and it guides evaluations of situations: what is seen as positive and negative, and what contributes to achieving certain goals. Human-centered design is an example of such a conceptualization.

Considering that there is currently no coherent *conceptualization* of everyday practices with technologies in transitions, how would developing such a conceptualization benefit designers working in this space? First, such a conceptualization would lead to new approaches to the situations that designers and design researchers encounter, and will also indicate sites where design practices might intervene to contribute to transition goals. Such a conceptualization leads to new ways to address current pitfalls of sustainable technologies, such as risks of rebound effects, neglect of user innovations, and overlooking the way that technologies present ideas of appropriate practice. A conceptualization also connects to other relevant frameworks, with their own understandings of everyday practices and technologies.

1.8. The heat pump transition in the Netherlands

In this research, I develop this conceptualization in the context of an ongoing sustainable transition. This is the heat pump transition in the Netherlands. In the Netherlands, the built environment accounted for 28% of the total final energy consumption in 2023, with

[15] For Smith and other information scientists, ontologies, theories and mental models are closely related to conceptualizations (2003). From the agential realist perspective which I take in this dissertation, the ontological is closely entangled with the epistemological and the ethical.

approximately 67% of this energy used for heating purposes (Energiebeheer Nederland, akri). Cutting back energy demand for these purposes is therefore an important target for reducing environmental impacts. Implementing heat pumps for residential buildings on a large scale should reduce CO_2 emissions and save energy while providing comfortable indoor climate of homes. These heat pumps are replacing the gas boiler systems commonly present in most Dutch homes (van der Bent et al., 2022). Implementing heat pumps successfully from an energy efficiency perspective in the existing Dutch housing stock typically requires material changes to the building. Due to lower supply temperatures compared to gas boiler systems, additional insulation might be needed, and existing heat distribution systems (such as radiators) might need to be replaced with low temperature systems such as underfloor heating or heat convectors.

The Dutch heat pump transition is a societal transition in the sense introduced above (Loorbach et al., 2017). While the case in this dissertation is that of a specific technology[16], the heat pump transition in Dutch society is not just a matter of technology roll-out, but has institutional, social, cultural, and organizational dimensions (Hajarini et al., 2022; Itten et al., 2021). For example: the heat pump transition requires changes to energy markets and regulations. It also prompts new collaborations between technology companies, resident associations and social housing organizations, to name just a few challenges (Lockwood & Devenish, 2024)[17].

The dimension of everyday practices is important in the Dutch heat pump transition. Heat pump performance (how much energy and carbon emission is reduced compared to previous systems) depends in part on everyday practices of residents in their homes (Kazmi et al., 2022). Practices such as how homes are ventilated, the thermostat settings, and even furniture layouts can influence energy performance and indoor comfort (Thalfeldt et al., 2016). This effect is much stronger in the case of heat pumps than with previous heating systems. This is a consequence of the technical features of heat pumps. The heat pumps being offered in the context of the energy transition typically use a lower supply temperature, leading to a slower and more gradual heating, a lower maximum heating capacity and limited domestic hot water, compared to many previous heating systems. This low supply temperature heating also leads to a different experience of comfort (more spread over time and space than the immediate and concentrated heat from gas-based systems) (Winther & Wilhite, 2015). As a result, residents need to develop new responses to experienced comfort (for example, waiting some time until the temperature set on the thermostat is reached, or changing seat locations as residents get used to the absence of a single heat identifiable heat source). Another consequence is that with heat pumps, residents are

[16] The emphasis on this particular technology is in part a consequence of their low energy use, compared to gas boilers, which makes them the default choice in this transition. That does not mean that other heat generators and sources of heat are not considered. Other options include district heating networks or infrared heating.
[17] Moreover, this transition is additionally complicated by the need for additional renovations of homes. Heat pumps can rarely directly replace gas boiler systems. Currently, many homes are not sufficiently insulated to be heated with low-temperature heat pumps (Wahi et al., 2023).

often advised to intervene less, not only because some heat pumps cannot respond fast, but also because many thermostat interventions make a heat pump less energy efficient and can even lead to damage over time. Instead of resident intervention, automation works in the background to keep a stable temperature and allocate heating and hot water provision (Stopps & Touchie, 2021).

While the technology of heat pumps is not new, implementing them in a successful way proves challenging. The value chain of heat pumps encompasses the building, installation and renovation sector. This value chain is seeking ways to speed up the implementation of heat pumps. Meanwhile, new heating technologies are perceived by many citizens to offer no, or limited, benefits in everyday life compared to natural gas heating systems (Williams et al., 2018). A particular problem in this sector is the question of how to understand and deal with, what are considered from an engineering perspective, unintended use patterns (Guerra-Santin, 2013; Winther & Wilhite, 2015). Since this engineering-oriented sector has little experience in dealing with end-users, they are increasingly seeking support from designers and design researchers in understanding how to increase the uptake of heat pumps in the Netherlands (e.g., Moore et al., 2015). This has led to a role for design research in the project Integrale Energietransitie Bestaande Bouw, of which this PhD research is a part (Integrale Energietransitie Bestaande Bouw: Programma Document, 2020). Within this project, this research is situated in subproject 8.1. *'configurator for heat pumps'*, and collaborates with partners from industry (heat pumps and solar technologies) and universities of applied sciences. To this project, the research has contributed with insights from ethnographic research that support a better fit between resident and configured heat pump system. It has also contributed to an understanding of how the configurator is embedded in renovation processes, especially where it relates to household practices. These contributions to the consortium project are made in workshops and project meetings. For this dissertation, these contributions provide context and motivation for asking broader questions about transitions and technologies.

As argued in this section, design in relation to heat pumps has to address societal goals of reducing environmental impact, and has to deal with changing configurations of everyday life and technologies. This makes the case of heat pumps in the Netherlands an interesting and representative case of technologies in societal transitions.

1.9. Research objective and research questions

The main objective of this research is **to develop a conceptualization of everyday practices with technologies in transitions that has actionable implications for design practices within these transitions.**

This dissertation will develop answers to four specific research questions that break down this objective:

Research question 1: How can this conceptualization be applied to everyday practices with heat pumps in the heat pump transition in the Netherlands?

Research question 2: How might this conceptualization contribute to questions in the domains of (1) societal transitions and (2) the value chain of technologies?

Research question 3: How might relevant dimensions of everyday practices with technologies in transition be operationalized for design?

Research question 4: What are sites of intervention for design practices in transitions that follow from this conceptualization?

1.10. Research approach

Over the course of this dissertation, I develop a new conceptualization of everyday practices with technologies in transitions. I do this, with the purpose of being of value to design research and to the problem of designing for the uptake of technologies in transitions. My approach is to bring ethnographic work in dialogue with dominant (human-centered design) and emerging conceptualizations (co-performance and others). This encounter results in the highlighting of several notions that are relevant to everyday practices in transitions towards sustainability, but currently under-explored in human-centered design; most notably the notion of 'improvisation' in relation to practices. I further test this conceptualization on its 'rational sensibleness' and 'usefulness' (Schatzki, 2016) by introducing it to problems in 'the field' (addressing research question 2). Over the course of this engagement with other fields, the conceptualization inevitably changes and is extended with other aspects and concepts.

My epistemological and ontological commitments in this research roughly align with contemporary forms of realism. They are inspired by and share some features with agential realism developed by Karen Barad (1996). Realism assumes that there is a reality, and that this reality is knowable. However, in contrast to classical forms of objectivist realism, agential realism contains no (strong) division of the object researched, and the subject doing the research. In this sense, agential realism aims to move beyond relativist critiques of positivism. On the one hand, it denies an objectivist 'view from nowhere'. On the other hand, agential realism does not want to fall back to an extreme relativist position where subjects and language have no access or connection to a material world. Agential realism attempts to bring 'wholeness' (Barad, 2007, p. 170) to the project of knowledge construction by rejecting both the dichotomy of subject and object, and the dichotomy of (representing) discourse and (represented) material.

Concretely, this means that people do not obtain knowledge by separating themselves from the world. 'We know because we are of the world' (Barad, 2007, p. 185). There is no privileged position from which knowledge can be produced. Instead, knowledge production is participation in the world. Every kind of research is a way of interfering with the world in one way or another[18].

Agential realism does not prescribe a method. In this dissertation, I use a mixed methods approach. In line with agential realist commitments, I try to practice proximity and engagement with the subject matter, rather than distance. In the ethnographic work (chapters 2 and 3) I take the participants' view of their own everyday life and practices seriously, but I also bring my own analytical lens shaped by the language and (designer) position that I have available (what Barad would call the 'apparatus'). This (designer) apparatus is sensitive to the 'dialectics of problems and solutions', and to improvisation, experimentation and innovation. Analysis of the ethnographic data, and the ambiguity that comes with it, is enacted inside of the research, rather than only after the fact in an artificially separated analysis stage. Similarly, in the semi-structured interviews reported in chapter 4, I present tentative interpretations of the interviewees' statements back to them, which I then tweak based on their responses. This follows generally the recommendations by Mellander and Wiszmeg for agential realist research practices (2016).

Agential realist views also influenced the larger course of this research. This research aims to develop a conceptualization of everyday practices. This conceptualization is informed by a design perspective, but is also treated as an intervention itself (c.f. §1.10.1.). This conceptualization is not a representation of the world, reflecting it 'as it is'. It is an intervention that makes certain things matter. It is an articulation, indeterminate and 'of a searching quality' (Mellander & Wiszmeg, 2016). It should therefore be tested and evaluated with the domains having the problems (§1.5) it tries to address.

1.10.1. A nested interdisciplinary research process

In this PhD research, knowledge is generated in three different knowledge domains. As interdisciplinary research, it contributes to design research, but also to two adjacent disciplines, transitions research and building science. The reasons for this were given in section 1.5: the domain of heat pump use spans these disciplines, and design research has the potential to provide a bridge between them. There are several ways of designing a process for research that spans multiple disciplines. There is no agreed order of steps for doing interdisciplinary research (Newell et al., 2001). However, in earlier research, some principles have been found helpful in formulating the relations between disciplines. In the research process followed in this PhD, there is a clear case of the principle of 'guide and supply' (Balsiger, 2004) in interdisciplinary research. This principle, developed from the work of Pieter Zandvoort (1995), describes one possible relation between disciplines in interdisciplinary work. One 'guiding' discipline formulates a task,

[18] There are clear parallels between this stance and feminist situated epistemologies (Haraway, 1988). It is also clear from this description how such an epistemology and ontology lend itself well to research-through-design approaches. For one particular interpretation of this connection, see Vega et al. (2023)

which the second, 'supplying' discipline then addresses (which may have the most efficient means of solving the problem). In this dissertation, this 'guide and supply' principle is nested, as design research contributes to other disciplines, which ultimately constitutes a contribution to design research (figure 1.2.).

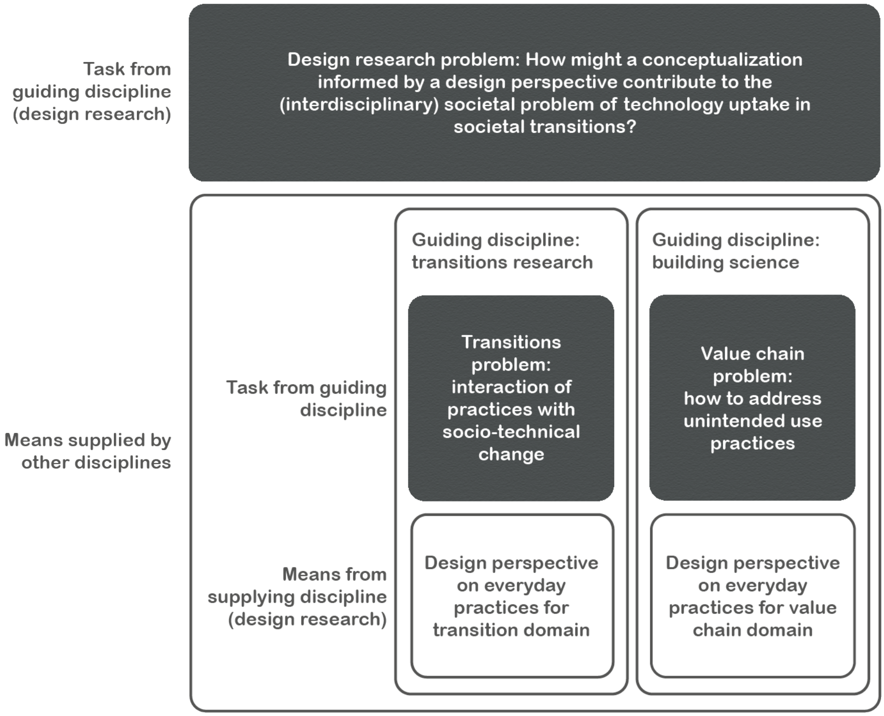

Figure 1.2. A nested interdisciplinary research process. A design perspective is brought to bear on questions in two different domains, forming the means to solve tasks in these domains. This process in turn addresses a problem in design research, which is how it might contribute to interdisciplinary societal problems.

Starting from the largest unit in figure 1.2., the dissertation as a whole addresses an audience of design researchers and contributes to the knowledge domain of design. However, the societal problem that it addresses (designing for everyday practices with technologies in transitions) cannot be adequately addressed by design research alone (c.f. §1.5). (At least) two other knowledge domains engage with this problem. In this dissertation I inquire (RQ2) whether a conceptualization developed from the discipline of design, might contribute to questions in the other domains. Research question 2 itself is a question for design research, that can only be addressed using the means of design research (developing a conceptualization). In the context of this dissertation, design research is the guiding discipline, formulating a task for two other disciplines, transitions research and building science. Research question 2 is thus addressed at the level of the dissertation, using design research, and answered towards the end of the dissertation.

Within this largest unit, there are two other units, in which the principle is reversed. Here, I use design research to supply its means (in the form of a conceptualization) to address the tasks formulated from the perspective of the two respective guiding disciplines (transitions research and building science). The problems and questions in the respective chapters (4 and 5) are formulated as problems and questions in the two respective knowledge domains. I call these two chapters 'expeditions' where I traverse disciplinary boundaries and venture into other disciplines[19]. These expeditions do not only aim to address problems in the respective 'guiding' domains of knowledge, but they also have their value for the objective of this dissertation. These expeditions return nuances, subtleties and implications for the conceptualization under development.

1.10.2. Methodological choices

The methodological approach followed in this research uses different methods to address different questions. In part it relies on (design) ethnographic work. And in part it makes use of research-through-design or more generally design inclusive research (Horvath, 2008).

Ethnography originates in the social sciences, in particular anthropology. Ethnography grounds knowledge creation in empirical observation, and field engagement with people 'in the real world'. One definition describes it as: *"iterative-inductive research (…) involving direct and sustained contact with human agents, within the context of their daily lives (and cultures), watching what happens, listening to what is said, asking questions, and producing a richly written account that respects the irreducibility of human experience, that acknowledges the role of theory, as well as the researcher's own role"* (O'Reilly, 2004, p. 3). Ethnography as a method has travelled into design research through HCI (Dourish, 2006), systems research (Crabtree et al., 2012), but also by blending itself with design (Pink et al., 2022). In the former, a form of ethnographic fieldwork is often used to inform design decisions. This typically means visiting and observing (potential) end-users of technologies. But Pink et al. introduce a more 'blended practice' (2022, p. 4) where ethnography does not just inform design, but 'is inseparable from design research and practice'. In this dissertation, I take inspiration from this blended practice of design ethnography. I use ethnographic techniques to understand everyday practices with technology. But design ethnography goes beyond being of use in

[19] An analogy which I borrow from Holly Robbins' PhD research (2018)

understanding. In this dissertation, it also aims at being an active participant and collaborator in developing solutions and making futures together with users and other stakeholders.

The main method of ethnography is known as participant observation, where the researcher participates in the phenomenon at hand. Ethnographers also conduct interviews and re-enact situations with participants (O'Reilly, 2004, p. 112). In this dissertation, when addressing research questions 1 (describing everyday practices) and 2 (contributing to the domain of societal transitions), I chose to combine features of these methods. Concretely, the ethnography is carried out as relatively short site-visits that include semi-structured interviews. I also rely on re-enactments, as many aspects of the phenomenon under investigation (everyday practices) cannot be observed directly. Activities become practices only when they are repeated, and many activities (such as thermostat changes) take place over longer periods of time. These activities are not just observations, but I participate in discovering solutions that people develop to the challenges that they encounter, which then have further impact when shared with other stakeholders later in the research project (Pink et al., 2022).

The research approach in this dissertation also uses more structured design activities to generate knowledge. Such an approach, in which doing design (or developing interventions) is a part of doing research, is sometimes called 'research-through-design' (RtD) (Stappers & Giaccardi, 2017) or 'constructive design research' (Koskinen et al., 2011). Often, in these approaches, a designer reflects on design activities. The activities themselves generate knowledge. In this dissertation, this is not the case[20]. Instead, design activities are used in two other ways.

First, addressing research question 2 (how the conceptualization contributes to the domain of building sciences), design activities are used to produce a design concept which plays a role in further study. This is similar to earlier RtD projects, where design is the basis of a user study (e.g. Bourgeois, 2016) and where design is used to provoke thought and reflection (Mazé & Redström, 2008). The outcome (and not the activity itself) is thus the vehicle of knowledge production, similar to the role of a stimulus in experimental research. This dissertation also relies on speculative design as a research method. Speculative design introduces design concepts with the aim of sparking conversation and provoking debate (Dunne & Raby, 2013; Johannessen et al., 2019). In this dissertation, I use it a way to sensitize research subjects in relation to research questions (Alfrink, 2024; A. Galloway & Caudwell, 2018). Design activities are used to make a video, which contains speculative design proposals.

The second way that design activities are used, in the context of this dissertation, addressing research question 3, is to generate intermediate level design knowledge (Höök & Löwgren, 2012). Intermediate level knowledge is situated on a continuum between the general and the particular.

[20] Design activities also produce tacit knowledge. In that sense, any somewhat reflective practice of design is *research through design*, but I do not report this knowledge in this dissertation.

It sits in between general knowledge (such as theory) and particular (such as a design concept). Intermediate knowledge can be of many types, such as guidelines, patterns, or methods. In this dissertation, this intermediate level knowledge consists of two design methodological proposals. These methods are operationalizations of the conceptualization developed in this dissertation (the general), without proposing specific design concepts (the particular). They do this operationalization by representing the world in a certain way. In this dissertation, these representations or visualizations are proposed to be of use in design processes and thereby address research question 3.

1.11. Main contributions

In section 1.9, I have laid out a research objective and four research questions that guide the research reported in this dissertation. The research objective is to develop a conceptualization, while the research questions ask how it can be applied to an ongoing transition in the Netherlands (RQ1), how this conceptualization might contribute to questions in other domains (RQ2), how this conceptualization might be operationalized for design (RQ3), and what sites of intervention follow from this conceptualization (RQ4). In the following, I describe which contributions are made by addressing these four research questions.

This dissertation makes five interdependent contributions. The first and primary contribution responds to the main research objective and is a *conceptualization of everyday practices with technologies in transitions* for design research. This conceptualization is initially presented in relation to ethnographic research findings, responding to research question 1, then further developed and validated as useful (responding to research question 2) and developed in relation to design (addressing research questions 3 and 4).

The second contribution of this dissertation is two-fold. I contribute a *conceptualization of everyday practices from a design perspective* to two different knowledge domains: transitions research and building science. Metaphorically, this contribution can be considered that which is delivered to other domains when venturing on an expedition from design research into those other domains (or unknown territories). In close relation to this is the second part of this contribution: a further developed conceptualization that has been sharpened by engaging with other domains. This can be thought of as what is returned or brought back from this expedition. Together, this two-fold contribution addresses research question 2.

The third contribution consists of *ethnographic findings on everyday practices with a particular technology* (heat pumps) *in a particular ongoing transition* (the Dutch heat pump transition). This set of empirical findings and observations is relevant to design research and other fields engaging with technologies in transitions, in particular those working on the Dutch heat pump transition. These findings and observations describe challenges and opportunities arising from everyday practices in the Dutch heat pump transition and could help designers understand how current interfaces, processes and communications could be improved. In developing this contribution, I also respond to research question 1.

This dissertation also contributes *two design methodological proposals designers could benefit from in design processes,* in response to research question 3. The purpose of proposing these methods is to support designers in highlighting the dimensions of everyday practices which are relevant when understood from the developed conceptualization. Designers might use this intermediate level design knowledge to understand everyday practices with technologies in transitions and develop corresponding design interventions. The methods propose the visualization of everyday practices as a movie script or screenplay (chapter 5), and the design capacities of technologies and users as design spaces (chapter 6).

Finally, responding to research question 4, this research makes a societal contribution in the medium of an animated video (originally used in the study reported in chapter 4). This video proposes a generative analogy (changes in everyday practices understood as improvisation on a script in a theater performance) and several *speculative design concepts* that direct to *sites of intervention* for design practices with technologies in transitions. This contribution is relevant to design and design researchers working in transitions, but is also relevant to other fields such as transitions research and building science. Realizing the value of the conceptualization depends in part on the extent to which it is taken up in practice. For this reason, I have made the video publicly available online with room for further feedback[21].

1.12. Dissertation outline

To summarize the above for the reader, figure 1.3. shows a visual overview of the dissertation, its contributions, the research questions, and relations between the parts. After this introduction, this dissertation is based on a set of loosely connected papers. Each chapter of the dissertation contains either a peer-reviewed journal article or a peer-reviewed conference paper or pictorial. The venues are diverse, reflecting the different fields we contribute to. There is some overlap in the background and related work sections of each chapter, but for a coherent argument I have left these in where they connect to the specific context and purposes of each chapter. In this introduction and in the discussion, I write in first person singular ('I') reflecting single authorship, while chapters 2-5 are written in first person plural ('we') to acknowledge the supervisory team's editing and conceptual contributions.

In the research reported in this dissertation, I investigate everyday practices with technologies in transitions. In this ***chapter 1***, I lay out the context and background and articulate the need for a conceptualization which might benefit the fields of design research, and other fields of knowledge concerned with technologies in transitions.

[21] It can be found here: https://youtu.be/BtMYS3fp0gM?si=IiQgcz-pyjUX1vvk

The central chapters of this dissertation are grouped into three parts. **Part I: Improvisation** introduces the conceptualization of changes in everyday practices with technologies in transitions as improvisation, that is central to this work.

Chapter 2 responds to the *main research objective* and introduces the central conceptualization on the basis of ethnographic research. In chapter 2, everyday practices are conceptualized as *co-performances*, indicating that humans and technologies perform everyday life together, with potentially *conflicting ideas of appropriate performance*. *Everyday crises of routine* form a critical part of how these co-performances are *reconfigured*. In short, changes in everyday practices with technologies in societal transitions are conceptualized as *improvisation*. We also introduce a new notion of *interface*, enacted in practice, rather than designed. This conceptualization is based on ethnographic research on these everyday practices, specifically with heat pumps in the Dutch energy transition, and addresses *research question 1*. Chapter 2 is initially written as a stand-alone contribution to the field of human-computer interaction, which for the purposes of this dissertation, is regarded as a subfield of design research.

van Beek, E., Giaccardi, E., Boess, S., & Bozzon, A. (2023). The everyday enactment of interfaces: a study of crises and conflicts in the more-than-human home. *Human–Computer Interaction*, 1-28. https://doi.org/10.1080/07370024.2023.2283536

Part II: Expeditions introduces the conceptualization, which was originally developed from a design perspective, into two other fields relevant to technologies in societal transitions. Chapters 3 and 4 were initially written as stand-alone papers contributing to the fields of transitions research and building science. Due to the structure of this dissertation, and to provide evidence (by way of demonstration), whether the conceptualization might contribute to questions in other domains (*research question 2*), chapters 3 and 4 follow the conventions (linguistic and otherwise) of these disciplines.

Chapter 3 picks up the developed conceptualization and connects it to dynamics of transitions, specifically the Dutch heating transition. It addresses *research questions 1 and 2* by adding a further layer of analysis to the ethnographic study reported in the previous chapter. We revisit the ethnographic research data to explore how the developed conceptualization of everyday practices from a design perspective might contribute to challenges in transitions research. We identify three types of practice reconfigurations, which are necessary for, and have the potential to contribute to, the Dutch energy transition. These types are reconfigurations of *knowledge, routines* and *material*.

van Beek, E., Boess, S., Bozzon, A., & Giaccardi, E. (2024). Practice reconfigurations around heat pumps in and beyond Dutch households. *Environmental Innovation and Societal Transitions*. https://doi.org/10.1016/j.eist.2024.100903

Chapter 4 further develops the conceptualization and connects it to the field of building science. We use a sensitizing video that relies on the analogy of theater performances. We carry out semi-structured interviews with professionals in the Dutch heat pump value network to examine their responses to improvisation, and identify the factors influencing the response. We identify *ten possible responses* to improvisation from the technology supply side and *nine motivating factors* for choosing a response. We also propose socio-technical innovations connecting the supply side to everyday practices of use as sites of intervention for design. This is the chapter where *research questions 3 and 4* are addressed.

van Beek, E., Boess, S., Bozzon, A., & Giaccardi, E. (2025). 'Try this and see if it works for you': A new perspective on household improvisation and responses from heat pump supply-side actors. *Energy and Buildings,* 338, 115725. https://doi.org/10.1016/j.enbuild.2025.115725

Part III: Representations propose two visual methods for design that highlight and support the analysis of features of everyday practices relevant to the conceptualization. Chapters 5 and 6 were initially written as conference contributions in the field of design research.

Chapter 5 introduces the design methodological proposal of the screenplay to represent and annotate improvisational co-performances. This vocabulary is proposed as an instrument to analyze and anticipate the *temporal dimension* and *underlying ideas of appropriateness* in everyday practices with technologies. This chapter contributes to addressing *research question 3*. It was initially written as a pictorial conference contribution in the field of design research.

van Beek, E., Giaccardi, E., Boess, S., & Bozzon, A. (2023). Making a scene: Representing and annotating enacted interfaces in co-performances using the screenplay. IASDR Conference Series. IASDR 2023: Life-Changing Design. https://doi.org/10.21606/iasdr.2023.788

Chapter 6 introduces another design methodological proposal as an instrument for design: the notion of design spaces, to address designers'-, users-' and technologies-' *capacities to design,* which are confined by what is considered *appropriate practice*. This chapter also contributes to addressing *research question 3*. It was initially written as a conference contribution in the field of design research.

van Beek, E. (2024) Contours in Blurred Design Spaces: More-than-Human Participation of Artifacts in Design-in-Use, in Gray, C., Ciliotta Chehade, E., Hekkert, P., Forlano, L., Ciuccarelli, P., Lloyd, P. (eds.), *DRS2024: Boston*, 23–28 June, Boston, USA. https://doi.org/10.21606/drs.2024.443

Chapter 7 synthesizes this research. I reflect on how, in this dissertation, I develop a conceptualization of change in everyday practices with technologies in transitions as improvisation. After answering and reflecting on the research questions, I suggest future research and discuss the implications of this research for various audiences.

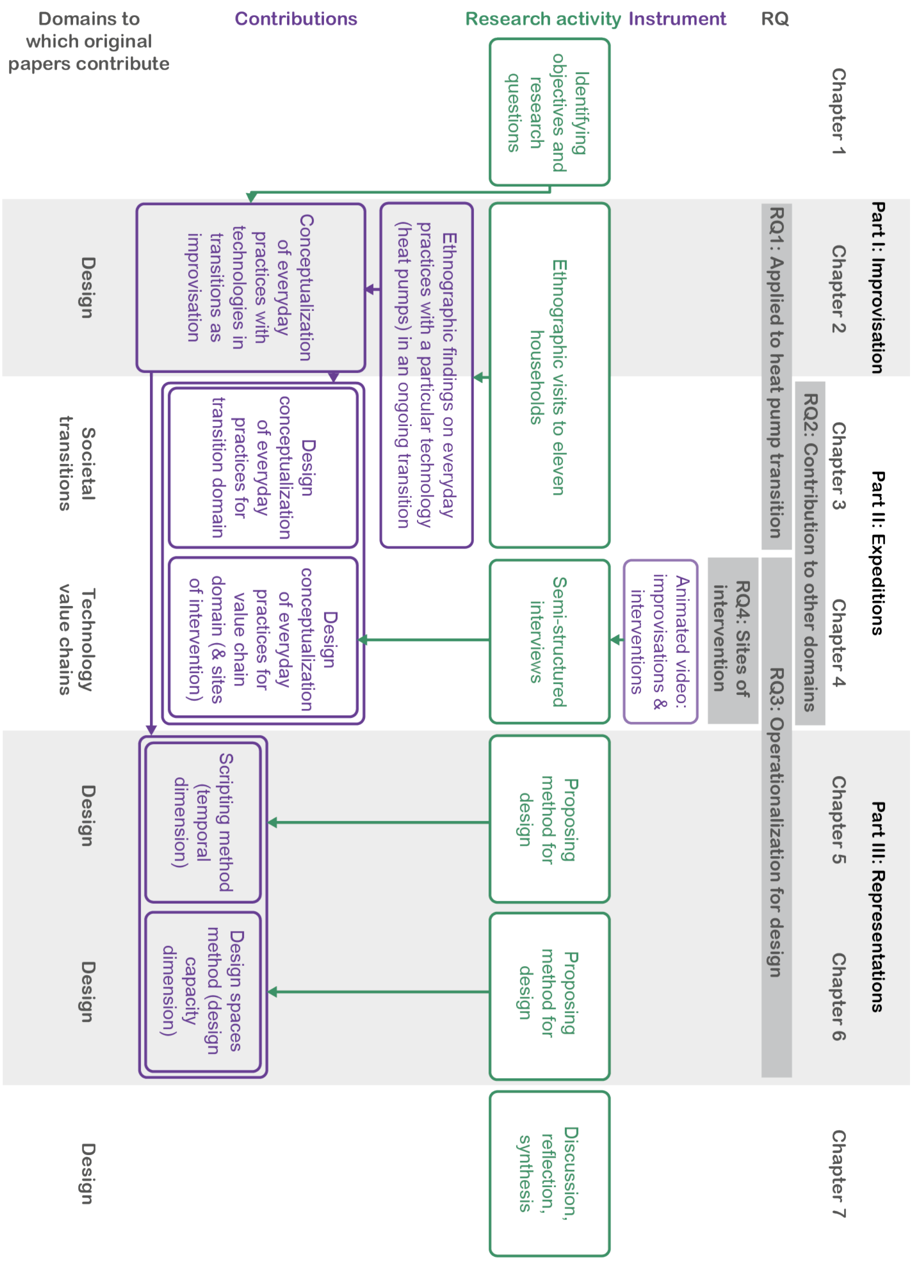

Figure 1.3. Visual outline of the dissertation

2 EVERYDAY IMPROVISATIONS IN THE MORE-THAN-HUMAN HOME[22]

The previous chapter has introduced the problem of designing technologies in transitions. In this chapter, we connect energy transitions with efforts and narratives in the field of human computer interaction aimed at achieving sustainability through 'smart buildings'. We deepen the argument that existing approaches, most notably human-centered design, are insufficient as a design approach for designing technologies that address societal concerns. Summarizing existing evidence for the messy reality of household on the ground, we argue that everyday practices, specifically those of households in transitions, are more messy than human-centered design conceptualizes them. Based on ethnographic site visits to homes with heat pumps, we offer an alternative.

We propose a new conceptualization of everyday practices with technologies, addressing the main research objective of this dissertation. Through a lens of *co-performance*, everyday life is performed by humans and technologies together, with potentially *conflicting ideas of appropriate performance*. *Everyday crises of routine* form a critical part of how these co-performances are *reconfigured*. Together, changes in everyday practices with technologies in societal transitions are conceptualized as *improvisation*. We also introduce a new notion of *interface*, enacted in practice, rather than designed. Finally, we argue that future design approaches should engage with the *temporal* dimension of everyday practice and the *design capacities* of technologies and users in transitions. This is developed in relation with, and applied to ethnographic findings of everyday practices with heat pumps in the ongoing research transition in the Netherlands, thus addressing research question 1 of this dissertation.

[22] The paper on which this chapter is based has been published as: van Beek, E., Giaccardi, E., Boess, S., & Bozzon, A. (2023). The everyday enactment of interfaces: a study of crises and conflicts in the more-than-human home. *Human–Computer Interaction*, 1-28. Compared to the published paper, edits include minor changes for readability and consistency (reference to other chapters, replacing 'UCD' with 'HCD', and consistent use of the term *crises of routines*)

2.1. Introduction

With the introduction of automated and connected technologies, we no longer just live *inside* our houses—we live and perform tasks together *with* them daily. In this chapter we will argue for a need to better understand this relationship. We will contribute to an understanding that goes beyond human-centered approaches, and that focusses on the relationship between humans and technology as it develops through crises in everyday practice. Drawing on more-than-human concepts, this chapter will propose the notion of enacted interfaces (new dynamic matches of people and things) as a way to conceptualize this relationship and how it develops. We develop these ideas further based on qualitative data from smart households in the Netherlands. Such an understanding is required to realize smart housing that acts sustainable and appropriate to the situation at hand.

By 2027, it is expected that more than 530M homes, that is, 23% of all households worldwide, will adopt at least one type of smart system (Ablondi, 2022). This is initiated by multiple actors for various reasons: Residents and housing owners increasingly seek automated support to ease various domestic tasks and save resources (Jiang et al., 2004; Strengers et al., 2020). In addition, many governments and municipalities have begun to incentivize the adoption of smart systems as key technological solutions to sustainable energy transitions (De Groote et al., 2017), with the goal of optimizing energy consumption and indoor climate (Mofidi & Akbari, 2020).

But, for smart home technologies to achieve their promises of sustainable energy consumption and support in domestic tasks (and prevent e.g., consumer rejection), these automations need to act appropriately to the situation at hand. Modern approaches, adopting a human-centered design (HCD)[23] perspective, prioritize human needs (such as fresh air and up-to-date information) to design automated, smart technologies to accommodate to those needs in an energy efficient manner (Agee et al., 2021). From this perspective the goal is to simplify, smooth out, and purposefully reduce the required interactions of residents with their homes ('set and forget') (Harper-Slaboszewicz et al., 2012). HCD is dedicated to preventing conflicts between humans and technology, especially by designing better graphical interfaces (Zhang et al., 2009), better prediction of human needs (Bouchabou et al., 2021), or better collaboration mechanisms (Huang, 2019). The assumption is that automation will perform appropriate actions in the background, meeting the users' intentions and actions without friction, and thereby achieving the promises of sustainable energy consumption and support in domestic tasks.

However, reality is messier (Strengers, 2014). From a resident's perspective, living with a smart building includes breakdowns, compromises, and conflicts (Davidoff et al., 2006; Hargreaves et al., 2018). In addition, governments, clients and commissioners find that building performance does not always save energy as predicted and hoped (van den Brom et al., 2018). For instance,

[23] In the published paper on which this chapter is based, we used the term user-centered design. See also the introduction for the motivation for adopting this terminology.

lights turn on in the wrong room (Geeng & Roesner, 2019) or technologies that are essential for health, such as ventilation, do not always function optimally (Boess, 2022). Through the lens of human-centered design, crises - i.e., situations of 'interpretative indeterminacy' where users do not know how to go on (Reckwitz, 2002, p. 255) - are something to be avoided, because they stand in the way of a smooth user experience. To HCD these crises indicate inadequate anticipation and faulty predictions of human needs by designers, and ultimately signify that automations did not act in a way that was appropriate to the situation.

This unfavored perception of 'crises of routines' contrasts with recent insights on everyday practice, where appropriate performance cannot be established beforehand (Kuijer & Giaccardi, 2018). In this chapter we adopt a lens informed by co-performance which puts the *appropriateness* of human and non-human performances in view. Through this more-than-human lens, it is not end-user needs that are highlighted. Instead, the focus is on how residents and the smart home perform everyday life together, on how appropriateness is negotiated and redefined through daily performances, and on the everyday crises of routine that form a critical part of how these co-performances develop and change (Kuijer & Giaccardi, 2018).

In this chapter, we apply this more-than-human lens to smart buildings. We inquire into the relationship of smart building technologies with their residents. Using this lens, we collect qualitative data using ethnographic walkthroughs in eleven smart households in the Netherlands, which we analyze with a focus on crises of routines, and what they reveal about conflicts between what people find appropriate and do when managing indoor climate and other everyday tasks, and what smart buildings do instead. We show how, studying smart households through this lens, yields relevant insights to design. These insights include a reappraisal of crises as opportunities for novel, more appropriate co-performances of humans and technologies. They facilitate the reconfiguring of human-machine relations to bring the system to interact and behave appropriately from a resident perspective.

We will also argue that our lens implies a different, more-than-human, notion of interface; from static 'human-centered' touch point to a new 'matching' that is dynamically enacted in the co-performance between residents and smart buildings. We wrap up with implications for the design of sustainable smart more-than-human buildings, where designers attend to, and possibly stimulate, the enactment of interfaces that do not smooth out crises and conflicts, but allow humans and non-humans to be responsive to one another (Giaccardi & Redström, 2020).

2.2. Related work

2.2.1. Smart homes and smart building interaction

Housing is a crucial component of life on earth. It provides people, animals and things with shelter and security, it stages live, work, and social interactions, and carries social meaning (Knox, 1987). The residential built environment also has a large share in energy consumption and greenhouse gas emissions, consuming 40% of EU's energy (Dascalaki et al., 2012). Driven by societal and technological developments in industrialized countries, making housing 'smart' is now increasingly considered as an opportunity to do housing better. The interest in smart housing is motivated by efforts to reduce energy consumption in response to the climate crisis, by technological developments that promise convenience for residents and building owners, and by a growth in senior population driving a demand for aging in place.

Yet, for smart housing to achieve its goal of reduced energy consumption and support in domestic tasks, smart technologies need to find a place in the complicated reality of situated everyday households.

The concept of smart buildings (or smart housing, smart home, etc.) is loosely defined by the inclusion of some form of automation of heating, ventilation and other 'building services', networked capabilities, sensors and actuators, and a user interface displaying e.g., energy consumption (Agee et al., 2021). The smart building is also considered a key element in smart grids and smart cities where communication and energy management takes place in larger networked infrastructures (Kim et al., 2022). In this chapter, we will refer to buildings as smart when they include most or all of these forms of automation or connection.

As more buildings are automated and connected, human-building interaction (HBI) becomes more complicated and has received increased interest (Shen et al., 2016). This has led researchers to suggest a more prominent role for the Human–Computer Interaction (HCI) community in the housing industry (Alavi et al., 2016). Simultaneously, researchers have developed arguments to adopt human-centered design principles, and import methods from HCI, in the traditional housing industry (Shen et al., 2016). In the next section we detail what this human (or user) centered design approach entails.

2.2.2. *Users in the center, technology in the background*

Within the housing industry (architecture, engineering, and construction), at least in Western countries, the traditional approach has been to employ a linear design and delivery approach, prioritizing cost-driven technology centered design (Agee et al., 2021). But, as noted above, with the interest in human-building interaction comes a call for centering humans in the design of smart housing. Drawing on Norman's seminal work (Norman, 2013), the imperative is 'to maximize human well-being and the operational performance of smart buildings' (Agee et al., 2021). Human-centered design is then directed to objectives such as human needs (thermal comfort), user understanding (readable symbols in interfaces), functionality and user experiences (joy). In design practice, it entails e.g., the development of personas, affinity diagramming, and iterative design approaches.

It is no surprise that the housing industry is seeking inspiration from the field of HCI to get a grasp on human-centered design. In studying computers and humans and how they interact, HCI has a longer tradition of explicitly centering the human user in the design of automated and connected technology. This tradition is characterized by a critical stance towards technology being pushed by industries. The principles of the HCD approach have recently been summarized in four objectives inspired by Norman's work: meeting user needs, making products understandable and usable, making products that perform desired tasks, and making the experience of using a product positive and enjoyable (Agee et al., 2021). Below we discuss some human-centered work on smart homes from the field of HCI and how these objectives are operationalized in the design of smart housing.

In line with these principles of human- and user-centered design (HCD), one dominant line of work in the design for user interaction with smart homes is focused on *predicting* and anticipating these needs. Human centered designers develop personas and affinity diagrams to predict smart home user routines, preferences, and lifestyles in the design process (Agee et al., 2021; Luo & Zhang, 2022). Once these future user characteristics are surmised, *control* is typically considered a priority user need which is then to be accommodated in design. A recent literature review seeks out 'tools for smart home control', for example (Caivano et al., 2018). This is confirmed by a literature review listing eleven prominent definitions of smart homes and finding that much of smart home technology narrative circulates around the notion of "control" (Dahlgren et al., 2021; Sovacool & Furszyfer Del Rio, 2020).

HCI for smart homes, in line with visions of ubiquitous computing (Weiser, 1991), assigns technologies a *background* role. This is done by, for example, predicting or inferring human needs in the background. Increasingly, automated recognition of human activity is seen as key to the future smart home (Bouchabou et al., 2021). Advanced algorithms and sensors should enable even better predictions of what users need in their homes (Du et al., 2019). The activity of (in particular, older) residents can be understood and recognized which then enables the smart home to provide its assistance where needed (Bouchabou et al., 2021)

Of course, smart home technologies are also imagined to provide a positive *experience* for the user. Rather than being sold on technological prowess, human-centered design recognizes that users are interested in pleasure and joy in daily life (Wilson et al., 2015). This aligns with work that centers user experience and emphasizes that for the user, the meaning of the home concerns emotions (Eggen et al., 2014).

Throughout this literature, we can observe a key role for *user interfaces* in the human-centered smart housing. This 'operational panel' (Zhao et al., 2016) should enable an easy initial setup, while providing the users with understandable feedback (especially about energy consumption), to improve transparency (Paternò et al., 2022) and intelligibility (Castelli et al., 2017), all to meet user needs without friction. Information should enable residents to control (and hopefully reduce) energy consumption in the home (Marikyan et al., 2019). The interface itself is thus the access point behind which the complexity of a system disappears (Norman, 1986). Once set up, users can forget about the functioning of the system (Zhao et al., 2016).

This literature reflects the premise that is prevalent in HCI for smart homes: the human-centered smart building smoothly fulfills pre-existing human needs. In summary: the smart building does its job in an energy efficient way, while any hiccup in everyday life is prevented and removed. The push by technology is replaced by a centering of the human; ergo, technology is cast in a background role.

2.2.3. *The elusive end-user in the messiness of everyday life*

We have described how human-centered design conceptualizes humans as individual beings with somewhat predictable routines emerging from pre-existing needs and desires, while technology fulfills those needs in the background. In this section we describe how everyday life in the smart home, as described in literature, does not conform to this conceptualization. We will contrast literature on the smart home with the characteristics presented above (*predictability, background technologies, positive experiences, user-oriented interfaces*) in our discussion of human-centered approaches to smart buildings.

While seldomly reflected in the visions for the human-centered smart home, life at home is found to be 'organic, opportunistic and improvisational' (Davidoff et al., 2006). Keeping the home in order, doing laundry, and organizing family life is a messy affair (Wilson et al., 2015).

This *unpredictability* presents a challenge for human-centered design of smart buildings which relies on assumptions of routines and schedules. Often, actual behavior does not match these assumptions (e.g., residents use a flexible mobile heating unit, rather than the provided thermostat) (Guerra-Santin et al., 2022). In response, researchers have proposed to increase granularity and accuracy in recognizing and predicting human behavior and intent (Bouchabou et al., 2021). However, it has proven to be difficult and costly to realize technology that knows where it can be of assistance to humans (Lee & Kim, 2020). Human intent is ambiguous and improvisational. Even more problematic to the goal of human-centered design is the question of whether users actually desire this assistance. Users described, for example, that assumptions made by the Nest learning thermostat, whether right or wrong, made it appear as 'arrogant' (Yang & Newman, 2013) and that they feared becoming a 'prisoner' of smart home technologies (Mennicken & Huang, 2012). The examples show that, within these messy circumstances, what residents do and what they expect from technology cannot be entirely predicted beforehand, and incorrect assumptions (such as the ones made by the Nest thermostat) might very well be detrimental to user *experiences*.

In contrast, existing literature finds that the 'right thing to do' arises within the situation at hand, and is negotiated among family members (Koshy et al., 2021). For example, a study with the Nest learning thermostat found that an occasional visit from relatives who prefer lower temperatures is already enough to surface a conflict between assumed and situated needs (Yang & Newman, 2013). These situated and dynamic needs arising from a complex context do not sit well with the inflexibility of automated technology.

Additionally, situation and context are not just external to interactions with technologies, they also include the technologies themselves. These technologies shape and create human aspirations and situated desires in everyday life. This insight is articulated by prospective smart home users who reveal worries about becoming 'lazy' when their life is automated (Balta-Ozkan et al., 2013). This capacity of technologies to shape their users, while broadly studied elsewhere (Akrich, 1992), seems absent from the framework of human-centered design where humans are expected to be accommodated (Kalvelage & Dorneich, 2014).

In everyday practices in the smart home, the technology often does not remain in the *background* as is the ambition in HCD, but becomes the center of attention. For example, a nine-month field trial found that smart home technologies disrupt everyday life, and that learning to use these technologies is a demanding and time-consuming task (Hargreaves et al., 2018). This learning requires high costs and effort, such as covering door locks with tape (Desjardins et al., 2020; Mennicken & Huang, 2012).

The display *interface* as presented in the human-centered smart home has an ambiguous role in everyday life. While it does deliver feedback about energy consumption and the current state of the home, and can be helpful (when well designed) to program the smart home, it is far from clear why residents in busy everyday life would further engage with a display on the wall (Buchanan et al., 2015). Encouraging active engagement by e.g., further reprogramming for technological optimization, or demanding attention regarding energy consumption, contradicts HCD's premise where technology should disappear in the background. HCD then assumes the display could serve as a control panel for various functions of the home (Zhao et al., 2016). Still, from the perspective of residents, why would a touch screen display in the living room be a more appropriate contact point for managing blinds than a point close to the window (van Beek & Boess, 2022)?

Crucially, these observations also suggest there is no guarantee that a human-centered smart home will lead to actual energy savings or greater sustainability (Tirado Herrero et al., 2018). The many irregularities in everyday life imply that a smart building might carry out what users want, but at the wrong time or in an inefficient way. This is confirmed by the (unfortunately, rather small amount of) empirical work that investigates the actual energy savings in homes that are smart and provide feedback (Chalal et al., 2020). The risk and reality of smart buildings is that a significant portion of them actually consume more energy than their non-smart counterparts (Tirado Herrero et al., 2018). Moreover, we mentioned that technologies shape human needs instead of merely supporting them. In the realm of energy savings, this phenomenon manifests in raising standards of comfort when a new, more efficient, technology is introduced. In this way, initial energy savings disappear in the long run (Walzberg et al., 2020).

To summarize: Everyday life in the smart home is *messy*, *unpredictable*, and shaped by *many other factors* than the (singular) human user and their needs. The literature presented here problematizes the assumptions and goals of HCD in everyday life with the smart building. By centering the human user, design tries to get a grasp on the user and fulfill their needs, but the unpredictability of everyday life and the many confounding factors between design ideals and technology in-use turns the proposed center of design into an unstable hold.

2.2.4. *More-than-human approaches*

When the human user of the smart building thus appears elusive and HCD is limited, it seems we need a different point of departure for HCI. Increasingly, HCI and design engages with theories, concepts and insights that find anchor points in other than human entities. This includes understandings of humans and technology which emphasize relations, technological agency and assemblages composed of humans and non-humans (Giaccardi & Redström, 2020). Originating from, for example, feminist theories and science and technology studies (Forlano, 2017), these more-than-human notions increasingly find traction within HCI (Coskun et al., 2022). While offering theoretic foundations (Frauenberger, 2019), new considerations (Coulton & Lindley, 2019), ways of knowing (Wakkary, 2020), and even new roles for designers (Yoo et al., 2023), until now more-than-human approaches have not been applied to everyday interactions with technology 'in-the-wild'. These approaches thereby remain somewhat distant from the process of designing smart buildings.

To address this gap, we think it is promising to take our starting point in the crises as they occur in everyday practice, which we have described as at odds with the concept of the human-centered smart home. In the next section we argue why the concept of 'co-performance' can be drawn on to better understand these crises, and what they tell us about the complex and dynamic relation between people and technologies. This will also enable us to further develop HCI's central notion of 'interface' in a field turning towards more-than-human issues.

2.3. The idea of co-performance

2.3.1. *A more-than-human perspective on agency*

The concept of co-performance has been introduced as a novel perspective on the role of artificial agency in everyday life (Kuijer & Giaccardi, 2018). Co-performance is based in theories of practice in HCI, which take everyday human activity, organized in practices such as bathing, cooking, and doing laundry, as the basic unit of analysis. Humans perform these practices in the messy and unpredictable settings of everyday life. The concept of co-performance takes this framework further (Kuijer, 2019), and argues that, since computational artefacts such as smart building technologies, are also capable of performing everyday practices, they should be considered as *co-performers*. Robotic lawn mowers and smart thermostats carry out tasks and judgements ('when to heat a room') alongside humans.

The concept of co-performance aims to enable HCI researchers and designers to develop richer accounts of the dynamic role of computational artefacts in everyday life, and related design practices. It has inspired design proposals such as a 'co-performing agent' that adapts its role in-use together with users (Kim & Lim, 2019), and a thermostat that learns about comfort-preferences (Huang, 2019). The concept has also been applied to envisioned frictions with learning systems, including smart buildings (Viaene et al., 2021), and suggested a way to deal with tensions and conflicts in automated decision-making (Jin et al., 2022) and to contribute to explainability in AI (Nicenboim et al., 2022; Tsiakas & Murray-Rust, 2022). Finally, the concept has informed a study exploring future summer comfort in the Netherlands (Kuijer & Hensen Centnerová, 2022).

2.3.2. Co-performance centers dynamic relations

Following practice theory, the framework of co-performance considers everyday practice as a dynamic location where change takes place (Kuijer, 2014). For example, the way individuals prepare and consume food is a social practice that is shaped by social norms and incorporates learned skills and material devices such as microwaves. However, every situated, everyday performance of a practice involves choices about what to eat, how to prepare food, and with whom the food is shared. An everyday performance can thus challenge or reinforce existing social norms and expectations, and in doing so, change the broader practice of cooking.

Co-performance recognizes the doings (or performances) of technologies as part of these practices. The everyday performances of microwaves and washing machines participate in performances of cooking and laundry. This implies that it is not just the human performer who can make a change in practices, but agency is located in the *relation* of human and technological performances. Concretely, when one or both performs their part of the practice differently, this can be the beginning of a change in practice. While designers of technology thus shape everyday practices, they often do not intend to change the practice as a unit. Instead, from a human-centered perspective, designers are primarily interested in mere support of common, already performed everyday practices. This influence of everyday practices on design decisions and vice versa, is referred to as the recursiveness of design and use (Kuijer & Giaccardi, 2018).

In the framework of co-performance, everyday practices involve know-how (an idea of how to appropriately perform an action) (Shove, 2016). Human performers enacting practices (e.g., laundry) integrate a know-how of appropriate practice ('judging what exactly is clean laundry'). For artificial co-performers this know-how exists in their specific embodiments and automations ('washing machine programs') (Kuijer, 2019). This technological know-how is based on an underlying reasoning about what is appropriate practice, originating in the design process. But what is appropriate in situated practice, cannot be defined beforehand, but is continuously reinterpreted by humans ('these clothes are not dirty enough to wash now').

This means that, unlike in a human-centered approach where human needs are determined beforehand, appropriate co-performance can only emerge in the dynamic and contested reality of everyday life. It is 'in practice' (within relations between humans and technologies) that divisions of roles and tasks, capabilities, and affordances manifest.

2.3.3. Crises of co-performances and the enactment of new interfaces

Ideas of appropriate action can be different between human and technological performers (judging 'how much detergent to add to laundry'). When these conflicting judgements manifest in everyday life, this can lead to 'everyday crises of routines' (Reckwitz, 2002). A crisis of routine refers to a situation where the human performers do not have a tested, routinized, socially agreed way to proceed ('normally, we don't run out of detergent so soon') (Reckwitz, 2002). In the case of a conflict, from a human perspective, this means that a technology messes up its judgement of appropriate practice ('the washing machine is wasteful, and adds too much detergent'). Humans might, however, be able to respond to these misjudgments, and repair or correct technological performances. In these *reconfigurations*, a new and improved match between human and system performances might be realized (limiting detergent supply in the washing machine), to which technologies again respond (by signaling a detergent supply error).

Noticing these opportunities for response and repair puts us on track of another aspect in which co-performance enables an understanding of everyday practice different from human-centered design. Typically, in HCI and from a human-centered perspective, the technologies in everyday life present themselves through a (designed) interface. The interface is the location or access point (Morales Díaz, 2022) where humans and technologies interact with one another, and where the 'problem of matching people to things' (Pickering, 2000) is solved. We have seen how, in the smart building, this often takes the form of a display or 'operational panel' (which hides the complexity of the actual technology (Hauser et al., 2023)).

However, adopting a more-than-human perspective, and shifting our focus from the way that technology presents itself (the aesthetics of the interface), to everyday co-performance, we might recognize many other and more dynamic forms of matching people to things. In co-performance, the interface appears not (only) as a pre-designed surface (Janlert & Stolterman, 2015), but as a doing. We might begin to understand interfaces as *enacted* in response to crises and in repair of co-performances. While literature in HCI recognizes that the pervasiveness of computing in everyday life requires renewed thought about the interface (Janlert & Stolterman, 2015), to date, there have been no attempts to further conceptualize the interface from the more-than-human perspective of co-performance.

2.3.4. The questions for our empirical study

With this framework in place, we can continue this chapter and turn our attention to everyday practices observed in smart buildings in the Netherlands. In our study, we focus on crises and new matches of humans and technologies enacted in practice. We aim to answer the following questions regarding the smart households in our study. Taking our starting point in crisis of routine, we ask: 1. Which ideas of appropriateness conflict? 2. How are the crises resolved? 3. How is a new matching (or interface) enacted? The key contributions of this chapter are a reappraisal of crises in everyday co-performances with smart buildings, and the beginnings of a more-than-human understanding of enacted interfaces in a framework of co-performance.

These contributions support the design of smart building technologies that reduce energy consumption while acting appropriate to the situation at hand.

2.4. Cases and method

2.4.1. Participating smart households

As part of the energy transition in the Netherlands, many building owners are aiming to reduce domestic energy consumption by implementing smart and sustainable building technologies. This includes heat pumps which include several forms of automation and are connected to sensors and smart thermostats meant to optimize heating performance and reduce overall energy consumption. This situation enables us to study smart building technologies in use, and empirically uncover how, in these households, ideas of appropriateness conflict, how crises are resolved, and new interfaces enacted.

The empirical part of this research consisted of ethnographic site visits and involved eleven households living across the Netherlands (table 2.1). As this research connects to a project exploring resident-heat pump interactions, recruitment criteria were the presence of a heat pump and some form of smart home technologies. Nine households living in a rented home were invited to participate through contacts at social housing and rental organizations. Two home-owner households were recruited directly by the researchers. The sample presents a balance of older and younger people, couples, families, and single dwellers. The buildings are both apartments and terraced houses, and their characteristics roughly represent the Dutch context. In the rented homes, the smart housing technologies were implemented by social housing organizations or technical partners. In these rented homes, we expect that conflicts might be more prominent, as renters have less possibilities to replace or change system performance, and technological judgements are 'backed up' by the technical expertise of professionals.

2.4.2. Sustainable building services

Buildings in our research are equipped with air-to-water, air-to-air or ground-to-water heat pumps (table 2.1.). Heat pumps heating water (and not air directly) work most efficiently with a smaller temperature difference between outside air or ground water temperature (the source temperature), and the water that flows through the system which heats the rooms (the supply temperature). For this reason, most heat pump systems are designed to work at relatively low supply temperatures, which heats indoor air slowly and steadily, rather than fast. In addition, high levels of insulation and a large thermal mass of building elements are seen as beneficial for heat pumps, as these factors limit the additional energy required to heat (or cool) the home following fluctuations in outdoor or indoor temperatures.

Both factors (low supply temperatures and high thermal masses) result in stable indoor temperatures which cannot be changed quickly by inhabitants. Several buildings in our research had these high levels of insulation, but others were buildings with older, less insulated designs, retrofitted with a heat pump with a low supply temperature. Sometimes, additional fans are placed within the convectors that move hot air (and thereby heat) quicker through the rooms.

2.4.3. *Integrated smart technologies*

Since heat pumps in the Netherlands are relatively novel (replacing gas-based central heating systems) and often implemented in efforts to save energy through smart technologies (van der Bent et al., 2019), they are frequently accompanied by other novel technologies. In the participating households, there were various forms of home management systems, automated sun shading, sensor-controlled mechanical ventilation (supposedly eliminating the need for ventilating through windows), lights with motion sensors, and various forms of connectivity and monitoring (table 2.1, figure 2.1.).

Table 2.1. Participating households and the human, animal, and technological performers of practices in everyday life.

<table>
<tr><th>Human and non-human living performers (pseudonyms)</th><th>Non-human technological performers</th><th>Building characteristics and situation characteristics</th></tr>
<tr><td>Herbert & Johanna</td><td rowspan="6">Automated ventilation system controlled by CO_2 and relative humidity sensor readings, thermostat in most rooms controlling underfloor heating, ground-to-water heat pump, domestic hot water boiler with scheduled reheating, automated exterior blinds controlled by outdoor temperature and wind sensor readings, automated light in several areas controlled by movement and light sensor, remote access by building technicians, energy consumption information on a display</td><td rowspan="6">Terraced house, completed 2020, social housing (location A)</td></tr>
<tr><td>Louise, one dog</td></tr>
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</table>

Human and non-human living performers (pseudonyms)	*Non-human technological performers*	*Building characteristics and situation characteristics*
Bas	Non-programmable thermostat controls an air-to-water heat pump, automated ventilation system controlled by CO_2 sensors	Rented, terraced house, 1970s replications (location B)

Figure 2.1. An impression of the smart home (left to right, top to bottom: a heat pump, cats and plants in the living room heated by underfloor heating, a graphical user interface with thermostat and a sensor, an automated light switch on the landing).

2.4.4. *Data collection and analysis*

Ethnographic walkthroughs

To investigate the crises in everyday practices, this research employed an ethnographic approach. Ethnographic methods are a well-established way of doing research in HCI, in particular for investigating how people live with smart technologies in their home (Pink et al., 2013; Strengers et al., 2022). Walkthroughs, where a home tour is complemented with reenactments of daily routines and technology interactions (Boess & Silvester, 2020) have proven useful to explore sensory aspects of everyday life, and to remember and imagine technology interactions (Pink, 2007; Pink et al., 2013). Methods from ethnography fit practice theoretical approaches to the everyday, especially in relation to design, because they allow for careful attention to material and improvisation (Pink & Mackley, 2015). Video recording enabled us to pay attention to technologies and material configurations during the analysis phase, rather than limiting ourselves to participants' statements in interviews (Pink et al., 2016). In the ethnographic interview we aimed for a depth of communication and mutual intelligibility on the topic of inquiry by asking for clarification and elaboration (O'Reilly, 2004). We also tested tentative interpretations with our participants. During the walkthroughs we aimed to establish rapport and trust. This gave us the possibility to ask participants clarifying questions later and share some slices of collected sensor data which could confirm or reject our interpretations.

As we are entering private spaces, where it is not feasible for a researcher to spend a long period of time, we could not observe the crises directly (Hitchings, 2012). Instead, we must rely on participants' memories, which we explored in collaboration with the participants through reenactments. In our research, one or two adult persons (parents) participated in the interview and home tour. This might have limited access to other perspectives, of e.g., children, guests, or pets.

Data collection was carried out by the first author in March and April 2022. Following signed consent, data was collected through a video-recorded home tour including reenactments of interactions and daily routines, combined with a semi-structured interview. Together, these lasted around 1,5 hours. Interviews and walkthroughs were digitally recorded and, where possible, transcribed for analysis. Written notes were made during and after the visits. Transcripts, video recordings and ethnographic notes were analyzed and coded in themes by the authors, with the aid of Atlas.TI software (ATLAS.ti Scientific Software Development GmbH, 2022)[24].

Selecting and analyzing crises

During the interviews, the topic of crises was discussed, specifically by asking how their practices had changed, what participants found challenging about living with these technologies, as well as more focused and contextual follow-up questions that arose. In the subsequent analysis, we further grouped our findings around emerging themes of crises. To identify them, we looked for instances where participants described their experiences as exceptional, non-standard, non-routine or non-mainstream. We also took note of situations where participants expressed uncertainty or where we ourselves felt that the situations were non-standard. Additionally, we identified crises where participants clearly deviated from the designed use. Lastly, we looked for characteristics of improvisation and experimentation, which further aided in our identification of crises. By taking a comprehensive approach to identifying and analyzing crises, we were able to gain a deeper understanding of the challenges and difficulties which participants faced in their experiences.

[24] Data and materials underlying this and the next chapter can be found on 4TU.ResearchData. https://doi.org/10.4121/32096b27-a9eb-4bc7-aaf2-73664241035a

2.5. Findings

In our findings, we take our starting point in the crises that we observed. In section 2.5.1, we describe how these crises reveal *conflicts*: underlying conflicting judgments about appropriate ways of proceeding. In section 2.5.2, we then examine how these conflicts become everyday opportunities for residents and smart buildings technologies to reconfigure the co-performance of residents and smart buildings with the aim to support outcomes that residents judge as appropriate. Finally, in section 2.5.3, we describe how new matchings are *enacted* (put into practice) in everyday life and identify the characteristics of such interfaces.

2.5.1. Conflicts: When residents and buildings disagree, and how this leads to crises

In this section, we show instances where the co-performance of human and technological performers did not play out in a way that was appropriate to the situation, according to residents. Although the technological performers in our research have capabilities to perform domestic tasks previously performed by their human co-performers, they did not always do this appropriately in the given situation. This leads to crises of routines. They put in view the conflicting judgments that arise between residents and smart building technologies about what is appropriate, meaningful, and useful in specific circumstances. These conflicts concern judgements about, for example, what technology should do when residents leave the house, when to cool the bedroom, when a room requires more lighting, and what are appropriate temperatures in the home. Conflicting judgments of appropriateness also occur among different household members (including pets). Three kinds of conflicting judgements were found. They are described in the following.

Situated versus decontextualized judgements

The first kind of conflicting judgment occurred when technology performed in a way that did not match what research participants found appropriate in a specific situation, even though system performance from a decontextualized viewpoint seems appropriate. In Gemma and Gideon's bedroom, fans in the convector can move air through the room and speed up warming it up or cooling it down. Normally, this system remains in the background: *"We never turn that thing on."* However, this system is automated in such a way that a fluctuation in temperature can cause the fans to turn on, which speeds up temperature corrections to the setpoint. This can happen anytime of day, including at night (figure 2.2.). This conflict led to a crisis in routines: *"But sometimes it starts cooling by itself. Starts to blow really loud. And then we quickly press the buttons, and we can go back to sleep."* (figure 2.3.). In this example, humans, situated in sleeping routines, judge appropriate technological performance different from the technology, which is designed from a decontextualized setting in which fast temperature corrections make sense.

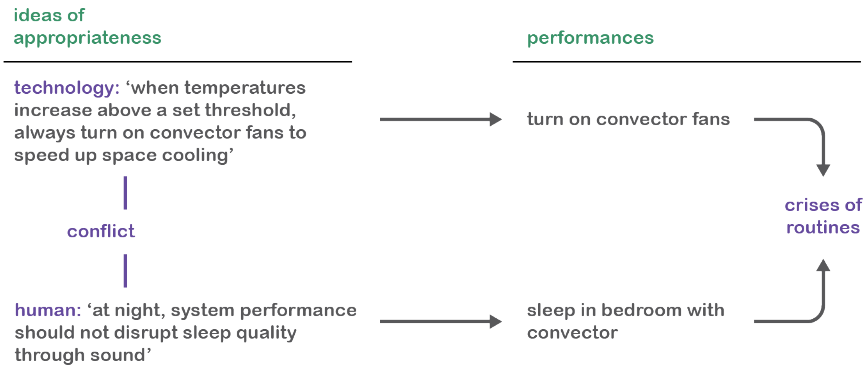

Figure 2.2. Crises of routines, human and technological performances, and conflicting ideas of appropriateness in Gemma and Gideon's everyday routines.

Figure 2.3. Gideon demonstrates how the family quickly press the buttons at night in response to the loud noise of the convector fans.

Another instance of conflicting judgment also occurred in Gemma and Gideon's home. The automation in the domestic hot water system will (in its default setting) heat a new batch of water only once every 24 hours. Given the limited boiler capacity, this is not enough for a full day of hot water for their family of six. This sometimes initiated a crisis in showering routines. "*It is kind of a puzzle sometimes. Who's going to take a shower when? (…) We have to make calculations. One time our youngest had a cold-water shower*". They are careful with the amount of hot water they use for doing the dishes to make sure there is enough for the kids to take a shower. *"The boys play soccer on Monday? Then we [parents] can take a shower on Tuesday."* This can be interpreted as differing judgments between humans and building designers about appropriate living situations. Gemma confirmed this interpretation: *"our family is too large for this house"*.

Diverse measures of success

The second kind of conflicting judgment relates to criteria for success. Some participants live more frugally than was assumed in the building design. This resulted in crises, as for example participant Louise explains: *"I find it strange that I don't have any influence on the temperature. When I leave [the house], I would want to lower the temperature a bit, but it just doesn't do that."* In this case, since the building is well-insulated, lowering the temperature for a short time may not reduce net energy consumption much, and reheating may take a long time. A stable temperature makes sense from a decontextualized designer perspective that views the building in terms of technical functioning and assumed human comfort. However, Louise's routine practices and understandings of sustainability include always striving to save as much energy as possible, resulting in conflicting judgements about the heating of an empty room.

Conflicts can also become visible in the sensory aspects of everyday life. Louise explained her morning routine and points to the home management display: *"Well, here it shows on the display that everything is 'good, good', and the ventilation is on medium, but I want that ventilation lower, because I can feel the drafts constantly."* This conflict reveals that Louise judged the appropriate response of the ventilation system differently (she does not like the drafts) than the automated technology (which keeps ventilating even though air quality is 'good'). Both examples reveal how residents and building services apply different measures and criteria for satisfactory indoor climate.

Inadequate system sensibilities

The third kind of conflicting judgement found, relates to the sensibilities of automated building technologies. Robert and Barbara vividly recalled a story involving the nighttime activity of their neighbor's cat. As the sensors for automated lights pick up on the cat walking by, a crisis occurs: the hallway lights wake the human residents, disrupting their sleeping routine. This example illuminates how human (and non-human) judgments of appropriate lighting schedules conflict. The home automation is set up for (and sensitive to) human activity requiring light in the evening, yet becomes inappropriate to the compound routines of a household with pets (which the system can also sense).

2.5.2. Reconfigurations: How the crises are resolved

In the previous section we have shown that crises reveal conflicts. In this section we show that residents take crises as opportunities to actively respond to these conflicts. They do so by reconfiguring (Laakso et al., 2021) everyday life in terms of routines, material settings or by reconfiguring system performances. Residents' responses range from attempts to reprogram the system, to tricking the sensors and manually opening and closing windows. Through these reconfigurations they change the relation between human and technological performances, and by extension their relation to designers and landlords. We found three kinds of reconfigurations.

Doing it yourself

Firstly, when a system performed inappropriately, residents in our research responded by partially abandoning the system, or they manually performed tasks which were previously automated. Partial abandonment often seemed to be motivated by a lack of possibilities that renters have to replace technologies or change their performance. Dustin explained how a crisis in heating and cooling routines revealed a conflict in comfortable temperature: *"So, it [the thermostat] is supposed to adjust automatically to the temperature in the room and (…) outside. To keep it comfortable for anybody living here. (…) I just keep it there, assuming that it's doing something."* However, the system performance could not keep up with what he considered appropriate temperatures. While keeping the automated heating system present in the background, he relied on windows and additional heaters to compensate where system performance fails. "*When it's not enough I can sometimes turn the heater on. Or open the windows."* Dustin's response was a reconfiguration of heating and cooling performances, to which he added his manual interventions of heater and windows.

Bas recalled that when he came home in the evening during the first months of his stay, he set the temperature higher, but this did not ensure a comfortable evening on the couch. He explained how he remembers to turn up the thermostat to a set temperature of 22, which he prefers in the evening. *"It tries to get to 22 degrees. I turn it on in the morning. And it takes a long time".* The reconfiguration in this case is Bas' additional manual adjustment, which he incorporated in his own daily routines to make the smart heating work.

Reconfiguring material settings

Secondly, we found that participants in our research reconfigure the material settings of everyday life to resolve crises. In Gideon's smart home, a crisis occurred when the kids couldn't sleep on summer evenings. The automated system judged a change in wind to be enough to open the sunshade. *"It just opened and then immediately closed again. Open, close."* Their response is to bring in an additional manual shade on the inside, which is closed on summer evenings (figure 2.4.). *"So, 9 out of 10 times, we just do it ourselves."* The residents reconfigured material settings in such a way that the automation will have less impact on sleeping routines.

A crisis in their son's work-from-home routine revealed how Alice and Rudolph have conflicting judgments with their son about what is an appropriate temperature in the home in winter. *"He likes the holiday temperatures, you know. 25, 26 [degrees Celsius]. Like the [elderly] neighbor."* They continued everyday life by installing an additional electric heater in the room where their son works. Here, the reconfiguration of material settings (installing a heater) is linked to a new human routine (turning it on during working hours).

Re-programming system performances

Secondly, we found that the programmability of smart house technologies enables co-performances that deviate from the designed 'use' of these systems. Rudolph, for example, explained how their son's sleeping routine came into conflict with the noise made by the ventilation system. Together with his tech-savvy son, he found a hidden control setting that, temporarily, sets the ventilation system to make less noise. After this, the system will automatically return to normal performance. *"This is actually meant for the engineers. You go to this web page, and you can set it back to zero. […] He kind of hacked the system."* Rudolph and his son have resolved this crisis by (in this case: temporarily) reprogramming the system's ventilation performances.

In Laura's house a crisis occurred when the smart lights turn off after a short period of time. *"Our youngest really likes to sleep with the lights on at the landing upstairs."* In response, the family has circumvented the automation, by turning it off for a while every night. *"So, when he goes to bed, we put it in 'lock' so that it stays on. And if we go back upstairs, we put it back so that it turns on when you walk by".* In this case, the (temporary) reprogramming of automation is closely linked to evening routines.

Figure 2.4. Gideon demonstrates the retrofitted manual sunshade with the automated sunshade on the exterior of the window.

Sebastian showed how he goes even further in reprogramming automations. His self-installed heat pump system is automated in such a way that it often repeatedly started with a loud noise and then stopped when there is a low need for indoor heat. This disrupted family life and conflicted with ideas of appropriate performance. Sebastian has changed the settings (the 'heat curve' and 'hysteresis') to resolve the conflict. Here, a more intensive reprogramming of system performance was required to resolve the families' crises and make heat pump performance appropriate.

2.5.3. Enacted interfaces: How a new matching between people and technology is put into practice

So far, we have shown that residents reconfigure their relations to smart building technologies in a variety of ways. They do so to modify the response of smart building technology in specific situations, to one that is more appropriate to their everyday lives. In this section, we describe situations in which these reconfigurations also enact (i.e., put into practice) a new matching of people to things (i.e., an *interface*) which persists in everyday life. In what follows we focus on how the everyday interfaces observed in our study are different from the graphical user interface intended for a 'set-and-forget' form of automation, and how everyday interfaces seem to work better in the residents' judgement of appropriateness.

Constructing new routines

First, rather than interacting through a graphical user interface, residents in our research align and consolidate co-performances through everyday activities. Opening and closing of windows and doors were frequently mentioned as ways to bring human and technological performances in line with residents' judgments of appropriateness. Herbert, for example, explained how daily routines of window opening and closing replace engagement with the thermostat. He does not touch this thermostat interface *"as we were told"*. Instead, on our following walkthrough, we came to frequently discuss opening and closing windows in different rooms as means to manipulate the temperature. *"Because that's how we like it."* Effectively, the opening of windows is a more trustworthy interface to achieve cooling than the automated system. In a similar defiance of instructions, Robert said: *"My wife opens the windows in the bedroom in the morning. But the advice is that we should actually not do that, because the air is circulated."* Residents find that the instructed use of the windows (keeping them closed), does not lead to what they find appropriate (the feeling of fresh air from open windows). Residents enact a different interface by constructing routines of opening and closing windows.

Responding to one another

Secondly, we find that the activities of residents are responses to system performances, which then in turn respond back. Through sequences of such responses repeated in everyday life, these interfaces persist. Gemma recalled that when the automated lighting in the bathroom turns off, she responds by making some movement. This brings the system back to appropriate performance. *"We sometimes have to wave to the sensor when on the toilet."* In this case, the interface is not set once, and then forgotten about, but a frequent 'back and forth' (or responding) of correcting the performance of the automated lighting enacts an interface that works for Gemma's family.

This 'back and forth' was also found in the way indoor temperature was managed. Gemma turned on the underfloor heating using the thermostat, which she leaves to a high temperature until the room becomes too warm. Gemma: *"In winter we sometimes have cold feet, and then we turn on the underfloor heating. But we also quickly turn it off because it gets too hot."* The interface, in this case, is not (just) the thermostat or the display showing the temperature. Much more significant is the response of the floor, and the responding of residents to cold feet. This mutual responding is notably different from the typical intended usage of a thermostat which is set to achieve and maintain a room temperature (figure 2.5.). Rather, the interface in this case is a repeated mutual responding of residents to heating, and heating to residents.

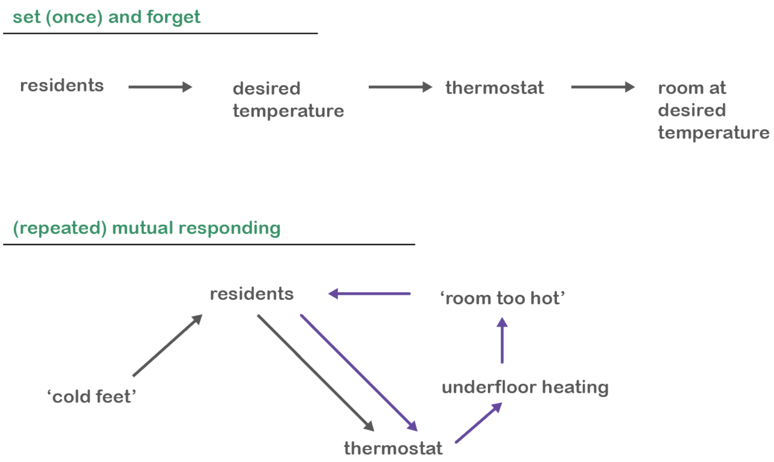

Figure 2.5. Typical intended usage of a thermostat ('set-and-forget') and a repeated 'back and forth' as recalled by Gemma.

The interfaces we found in our study are not a single button, passively present in the background to 'set-and-forget' the building automation. Rudolph and Alice were frequently presented with a crisis in routines when they entered the scullery that has automated lighting: *"It's great you can walk in with full hands and don't have to think about something. But it doesn't turn on when it is somewhat light* [outside]. *So, you're looking inside a dark cabinet."* In response to this crisis in routines, they have installed a manual sunshade. This device does not replace the system performance but alters its performance by changing the light sensor readings to become appropriate. *"We have added some extra shading which we roll down, so the automatic lighting turns on."* (figure 2.6.). This material device is not automated, and thus, in a sense, less 'smart' than building and residents. However, it is in an important sense part of both human performances (being closed by Alice) and technological co-performance (blocking sensor readings). In this case, the interface, as a new matching, consists of both the material device and the activity of Alice and the lighting.

Figure 2.6. The retrofitted manual sunshade that can be drawn down to alter the light sensor readings.

Expanding the network of relations

Thirdly, we found cases where interfaces in our research are embedded in the complicated multiplicity of everyday life. In the home, all kinds of performances are present and interact with one another. Here, the interface does not just match the single human to a technology, but connects many more performers to one another in a network.

Newly enacted interfaces include, for example, the activities of pets and plants. Louise mentioned how her dog plays an essential role in determining the appropriate performance and location of the underfloor heating: *"Yes, the dog was lying down around this spot."* and *"What was really funny, when she [the dog] came out of the bench, she immediately ran to the water, she normally never does that, so yeah, I think she was thirsty."* Gemma similarly explained how the dog in their household prefers to lie on the couch, rather than on the floor in winter, since he finds the heated floor to be uncomfortable. Here, the newly enacted interface consists of the activities of, and the relations between humans, technologies, and dogs.

Figure 2.7. A plant that lost leaves in Julia's previous house.

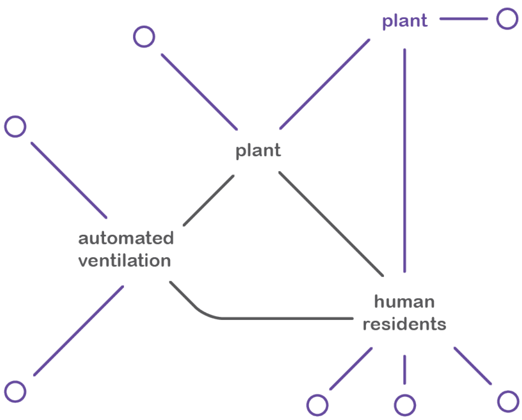

Figure 2.8. New relations between humans, automated ventilation, plants and beyond.

Julia mentioned plants as relevant to understanding the building performance. "Because in the other house, it was very bad. It was very humid and very dark. (…) This one [plant] looks bad now because of that house." (figure 2.7.). Their current house has automated ventilation, and thereby takes care of the dehumidification of the indoor air. However, this then required a change in the residents' routines of plant watering. "The [previous] house was humid, so I didn't need to water them so much. Here they have more light, but I need to water them much more." In this case, the activity of the plant becomes included in an interface that connects technologies and living entities into a network of relations (figure 2.8.).

In these examples, residents enact new interfaces by integrating other nonhuman performers into their daily routinised co-performance with the smart building.

Engaging human bodies

We found that the engagement of human bodies is another characteristic of the enacted interfaces. Whereas typical (designed) interfaces for automation are displays with a limited modality (often: a touchscreen), the interfaces we describe, engage with more sensory modalities of physical human bodies.

Louise, as noted before, has little trust in what the display interface shows her about system performance. Instead, she invited us to experience system performance by taking off our shoes: "*And can you feel it? I feel immediately some heat around my feet when it heats up.*" Ella also demonstrated how she took a little walk around her house without shoes to feel where the underfloor heating pipes are located. Dustin invited us to share his embodied experiences as he notices the airflow when he sits on the couch in the evening: *"If you come here, you can feel that there is air coming […]. I don't know if it's cooling or…".* Bas, on the other hand, engages with system performance through the modality of sound. He particularly notices change in system performance during silent moments. *"I can't tell where it comes from. But I hear quite some buzzing and ticking sounds, especially at night."*

These examples highlight that interfaces that matched human and technological performances are not limited to touchscreens. Instead, they are embodied and sensory.

2.6. Discussion

In the empirical part of our research, we have looked at everyday practice in smart buildings as observed and recounted in our ethnographic walkthroughs. Prompted by earlier research and informed by the more-than-human framework of co-performance, we looked for crises in our empirical research. We have noticed that instead of smooth interactions, crises occur. By further investigating these crises we found that (1) these crises stem from conflicting ideas of appropriateness. What is appropriate, according to residents in situated use, appeared to have not been taken into account by designers in decontextualized decision making. These conflicts are further exacerbated by the different sensibilities and capabilities of humans (e.g., bodily felt temperature) and technological systems (measured room temperature). The differences in the way humans ('not feeling drafts') and technologies ('CO_2-levels') measure success further reveal conflicting ideas of appropriateness. We also found that (2) these crises are resolved through reconfigurations. Residents actively engage by taking over roles previously performed by systems, by changing the material configuration of their homes, and by reprogramming smart home technologies. Finally, we found that, as a specific form of reconfiguration, (3) new interfaces are enacted. These interfaces are persistent matchings of humans and technologies which are enacted through new routines of humans and technologies. These interfaces take the shape of sequential responses. We found that they may involve a network of non-human performers, and engage human bodies.

Smart homes are increasingly present in everyday life. We are not the first to study everyday practice in smart homes, nor are we the first to adopt ideas from practice theory (Jensen, Strengers, et al., 2018). Such earlier studies have also found that conflicts occur in the smart home (Mennicken & Huang, 2012). However, we are the first to use a lens of co-performance in such a study.

Our approach offers an alternative to human-centered approaches to smart homes. We consider human-building interaction (Alavi et al., 2016) not with technology in the center, nor from a human-centered perspective focusing on assumed end-user needs, but starting from what is in between—the relation between humans and technologies and how this relation can evolve to become more appropriate from a resident perspective. Taking this more-than-human approach highlights ideas of appropriate everyday practice embedded in human and technological performances, and how their respective capabilities and sensibilities enable them to respond when ideas of appropriateness come into conflict. By probing beyond static user needs and predictable interactions, our approach highlights that new interfaces are enacted by residents and smart buildings, which leads to them settling on a more appropriate co-performance.

Existing work that takes more-than-human perspectives in the fields of HCI and design has predominantly decentered the human user in favor of posthumanist conceptual and theoretical frameworks, and then used these theories and concepts to speculate on alternative roles and practices in design and HCI (e.g., Coskun et al., 2022; Forlano, 2017; Giaccardi & Redström, 2020; Nicenboim et al., 2023). The work presented in this chapter uses co-performance as a more-than-human lens to add empirical nuance to theoretical inquiry. This empirical focus has enabled us to probe how more-than-human concepts can be useful in analysis of existing practices, not just in speculative design practices. More importantly, though currently absent from dominant (human-centered) conceptualizations of the design process, we were able to observe that more-than-human design practices do take place in everyday life. Practices of negotiation, responsiveness, and reconfiguration (Giaccardi & Redström, 2020), engagement of non-humans (such as sensors, but also cats) (Wakkary, 2021), and the creation of spaces where humans and non-humans come together (Frauenberger, 2019) could all be observed in the smart home when taking a more-than-human orientation. Such an orientation positions the act of designing outside the formally designated design work by professionals and reflects our acknowledgement of end-user appropriation as a creative activity (Fischer et al., 2004b; Kuijer et al., 2017; Wakkary & Maestri, 2007). This orientation also suggests an initial framework and vocabulary for how more-than-human design practice can tap into practices of use, experimentation, and resourcefulness of human and nonhuman performers alike.

On this premise, we briefly expand on the relevance of our findings for HCI and sustainable design, and discuss implications of a more-than-human approach for the design of smart homes and automated performers in a broader sense.

2.6.1. *A reappraisal of crises as productive events*

We have seen that a human-centered approach to smart homes often aims to smooth out conflicts and crises within everyday life. Our study indicates that conflicts can be expected since it is impossible for designers to predict or fully anticipate what is appropriate in everyday practice. Our findings also show how these conflicts lead to crises of routines in everyday life, as smart building technologies do something different from what residents find appropriate. Yet, these crises also enable reconfigurations which then improve co-performances from a resident perspective. These reconfigurations are forms of situated adaptation (or 'appropriation' (Sørensen et al., 2000)) of smart technologies that make their performance appropriate to residents within everyday life. Human performers (end users) are (as of now) unique in their capabilities to initiate resolutions of these conflicts in improvisatory and resourceful ways. However, are there lessons to be learned for design? Designers of smart home technologies might support this appropriation by designing technologies that are more flexible and configurable and thus more open to improvisation (Kuijer et al., 2017). This appropriation can also be supported by professional human actors such as technicians or building owners who are involved in the use phase (Boess, 2022). These professionals could be supportive to residents in the resolution of crises by being open to learning about crises from residents, advising from a more technical point of view or adapting hidden system settings to make them more appropriate for residents. In addition, the (connected) smart building lends itself well to the extension of design activities (like optimization of settings) into the use-phase which enables designers to be involved more in everyday practice than possible before (Giaccardi, 2019).

More in general, this reappraisal of everyday crises as possibilities for reconfiguration entails a different positioning of design practice in terms of how it shapes technological performance in use-time. The challenge for design is then not one of discovering the intentions of residents (e.g., having warm feet) and then enabling the technology to act upon these intentions, like human-centered design has been trying to do (Agee et al., 2021). Rather, the challenge could be how to both learn from and possibly even stage crises in design time, and to then design with the reconfigurations and interfaces that emerge. We also propose an alternative to existing design research which is focused on changing user behavior for sustainability goals (Coskun et al., 2022; Lockton et al., 2013). Our intent is not to design for pre-determined resident behaviors. Instead, the challenge is to design a certain openness and configurability into smart buildings to relate and respond to human and other entities within the home.

This openness also implies a positive outlook towards improvisation and experimentation with technologies in everyday life (Giaccardi et al., 2016; Jalas et al., 2017). Rather than focusing on increased human control over technologies, *this paradigm challenges designers to offer human performers opportunities to experiment, learn and explore in a meaningful way with technologies*. This means that residents and smart buildings might perform more flexible roles where tasks can be dynamically delegated from humans to technologies and vice versa (e.g., users deciding 'I'll do it myself' or systems requesting manual interventions in automated performances).

2.6.2. *Interfaces enacted in practice*

The notion of interface is malleable, and the current more-than-human turn in HCI and design has not yet articulated a conceptualization of the interface. Almost 30 years ago, Cooper and Bowers (1995) claimed the user interface as the site of HCI knowledge and practice. They identify the notion of interface as flexible, and only accidentally, in their era, manifesting as a screen. Their analysis of HCI discourse recognizes that the entity of interface is produced through practices (discursive practices in HCI and practices of use) (1995, p. 64). Through the lens of co-performance, we have developed and mobilized a contemporary more-than-human understanding of the concept of interface. Rather than limiting ourselves to the 'operational panel', we looked at other 'solutions to the problem of matching people to things' (Pickering, 2000). In line with an understanding of everyday practice where residents and smart buildings perform everyday life together, we recognized many interfaces that are *enacted* rather than designed. These interfaces are 'zones of activity' (A. R. Galloway, 2012) that allow humans and non-humans to respond to one another in situations that are not, and cannot be, entirely anticipated by designers (Bødker, 2006). Through improvisations and experiments, residents and technologies figure out new matchings that persist in everyday life.

In contrast to the operational panel, the enacted interfaces are not of the graphical or representational kind, representing the state of the building to its occupants, to improve their understanding. They are also not the means to carry out a specific task or goal (as in (Blair-Early & Zender, 2008; Marcus, 2002)), nor an exchange of information primarily (Molich & Nielsen, 1990). In the smart building, where technologies present themselves more as 'fields' around humans, than as tools that humans use, the interface is almost 'faceless' (Janlert & Stolterman, 2015). Rather than (just) the surface of a screen, the interface is a site of mutual 'effects' and responses of human and technological performances (A. R. Galloway, 2012). Interfaces are new relations, enacted through household routines, and in relations with windows, and pets.

These interfaces relate and connect human and non-human performances through embodied couplings, and routines, human and non-human, that match and build on one another. This aligns with Suchman's proposal to 'take the interface not as an a priori or self-evident boundary between bodies and machines but as a relation enacted in particular settings and one, moreover, that shifts over time' (L. A. Suchman, 2007, p. 263).

For designers this implies a shift in thinking of interfaces not as nouns but as verbs. They are not about knowledge, insight, and control of a technology (i.e., designers developing the correct representations for users to understand how things work). Instead, interfacing is about the site where human and technological performances affect one another. Designing technologies and technological performances that enable the everyday enactment of this kind of interface is not straightforward. The challenge seems to ask designers to leave some margin: a certain flexibility and configurability in technological performances. Building technologies such as smart thermostats could be made sensitive to other measures of success than the room temperature. In this way, technologies might be able to respond to and develop with redefinitions of what is considered appropriate by residents in the course of everyday life.

To summarize, we have argued and demonstrated that what is an appropriate performance, for both humans and automated technologies, can change over time and therefore interfaces cannot be fully anticipated and materialized at design time. Instead, interfaces come about through the ability of human and technological performances to respond to one another. This suggests that, rather than the design of single touch points, *designers should focus on the cultivation of 'responsiveness', both human and artificial*.

2.6.3. *Designing sustainable buildings as more-than-human sites of friction*

A smart building promises to consume less energy and be more sustainable because its automations can do the necessary things ('user needs' such as heating, turning lights on) in a more efficient (energy saving) way than users. Our observations highlight that residents do not evaluate and reconfigure technological performances according to their 'user needs', but according to what is appropriate to the situation at hand. What is appropriate is situated, contextualized, and contested. Whether driven by mere technological possibilities or by a genuine orientation towards human needs, a smart building will always contain assumptions about what is appropriate everyday practice (how does one live there). Our research suggests that, if the performance of a smart building is optimized simply according to assumed current resident practices (or envisioned alternative practices), projected energy savings and sustainability goals might not be realized. For example, residents consider the opening of windows when heating appropriate practice. This is different from projected use, makes the building lose thermal energy, and consumes more, rather than less, energy.

The challenge thus seems to hinge on uniting the appropriateness and sustainability of building performance. Reading through the complexity presented in our findings, it seems an extraordinary challenge for designers to shape the co-performance in smart buildings in such a way that it is always efficient with energy, while also being appropriate to the situation at hand. The smart buildings in our research could not have been programmed or designed in such a way that they could deal with the contextual, situated nature of appropriateness as described by residents. This reflects insights from literature which consider technological artifacts as (for now) incapable of dealing with tacit, implicit and ambiguous information or social awareness (Kuijer, 2019, p. 208). When inappropriate performances can thus not be prevented, designing sustainable smart buildings becomes a matter of configuring performances that are flexible towards different and changing circumstances in the home, while remaining energy efficient (e.g., the heating could turn off when windows are opened). In this way, conflicts can be resolved and even be fruitful towards the enactment of new interfaces that allow new co-performances.

However, design for sustainable smart buildings does not have to stop at this seemingly neutral position towards everyday practices. Instead, our research emphasizes the ideas of appropriate practice embedded by designers in technological performances, which thereby shape everyday life in the smart building. By going beyond straightforward automation of tasks previously performed by residents, this power of designers can be used to direct or orchestrate sustainable co-performances. For example, a smart thermostat could slowly reduce set temperature over time, requiring active involvement of residents to stay warm, which might reduce energy consumption. Here again, our proposal is different from efforts to change behavior. Instead, we align ourselves more with efforts to provoke, negotiate, engage, and propose and explore alternatives (Jensen, Raptis, et al., 2018; Mazé & Redström, 2008; Pierce & Paulos, 2013).

This might very well go much further than merely the material configuration of building and automation (the linear approach to building design). Designers could devise everyday experiments together with residents (e.g., new routines), be engaged in instructing them during use-time (e.g., suggest to 'notice the dog's behavior'), or adapt system performances during the occupancy phase. Rather than avoiding crises, these design activities might foreground conflicting ideas and thereby be influential in making everyday life more sustainable. This extends previous design research, which has e.g., put design efforts in 'crafting an argument' for different behaviors towards end-users (Mazé & Redström, 2008). Our suggestion goes further and proposes that end-users are also enabled to 'speak back' to the argument proposed by designers.

From a co-performance perspective, the everyday crises we presented, can be seen as conflicts about sustainability between residents and technologies (and, by implication, designers). They come into everyday conflicts about the importance of sustainability, what it means, and what are effective ways to realize it (e.g., when to heat a room). This further foregrounds the home as an 'inherently social, political, and contested site' (Dahlgren et al., 2021).

With these considerations in mind, the enacted interface is not just a site of productive friction but can be interpreted as a site of deliberation. *Designers might turn their attention to design for conflict and deliberation and consider how it might turn into a productive dialogue.* More speculatively, this can be considered as a more-than-human form of participatory design through and with technologies

(Hee-jeong Choi et al., 2020) or 'particular instances where the dynamic agency of algorithms comes into relation with human actors, citizens, and the public(s), especially when it resists automation'. This positions human designers in the role of infrastructuring co-performances (Karasti, 2014), which expects of them an 'attentiveness to existing power asymmetries' (Barad, 2007) and an awareness of political agendas and narratives in technology development.

2.6.4. *Limitations of the study*

Our ethnographic method informed by a practice theoretical framework focused on crises of everyday routines. This focus might have limited our perception of everyday life as it unfolds more smoothly, and we might have overlooked other ways in which human and technological judgments influence one another. In addition, our sample of participating households featured a high number of tenants. Thereby, many decisions regarding design, choice and implementation of smart home technologies were made by professional stakeholders (housing organizations and technical stakeholders), rather than residents acting as consumers. This might have led to a higher acceptance of technological judgements justified by the 'expertise' of professional stakeholders; judgements which residents would otherwise not consider appropriate. On the other hand, this different type of relationship between residents and technologies seems to prompt residents to engage more in conflicts with technological judgements, which they, as tenants, did not have the power to change.

By situating our research within the boundaries of the household, we have not engaged with potential future developments on a societal scale that might have a bearing on the appropriateness of everyday practices in the home. One could think of increasing energy prices as examples of developments that change norms. In future research, the crises prompted by such developments could potentially also be studied through the lens of co-performance. We have also limited our scope to the physical walls of the household and thereby not engaged with the many other-than-human agencies and perspectives that emerge when smart buildings are connected to broader networks (Coulton & Lindley, 2019; Redström & Wiltse, 2019).

We relied on the memory of our participants and a shared exploration documented on video. As the data has been gathered principally from the human side of co-performance, we might have missed out on the less visible aspects of technological performances. This limitation could be compensated for in future research by capitalizing on increasing opportunities to gather more insight into past and present technological performances through for example, building monitoring (Guerra-Santin et al., 2017) and the attachment of sensors to devices (Berger et al., 2019).

2.7. Conclusions

We live with our smart houses, not just inside them. Using the more-than-human lens of co-performance, we hope to have contributed to an understanding of what living together in the more-than-human home looks like. We have argued for a reappraisal of everyday crises of routines as possibilities for improved co-performances. Our empirical research through the lens of co-performance revealed how crises of everyday routines reveal conflicting judgments between human and technological performers of what is appropriate proceeding. We have argued that these crises are opportunities for the reconfiguration of relationships between humans, technologies, and other entities.

Through the lens of co-performance, we have developed and mobilized a more-than-human understanding of the object of HCI, the interface. We have shown that new interfaces between human and non-human performances are relational matchings enacted in use, dynamically subject to change.

We have suggested that researchers and designers look beyond human-centered approaches, and instead focus on more-than-human relations in everyday practice. Rather than stable anchor points, these relations provide a starting point for investigating dynamic and fluid co-performances. We have also suggested that designers could focus on the cultivation of responsiveness, both human and artificial, to enable the enactment of new interfaces and support sustainability and dialogue about this issue in the use phase.

In future research, the enacted interfaces and co-performances could be studied in further detail and from other (non-human) perspectives using sensors and other data gathering devices. Future research could also explore the opportunities of designing technologies and technological performances that enable and promote the everyday enactment of interfaces, which offer human performers opportunities to experiment, learn and explore in a meaningful way with technologies.

3 EXPEDITION 1: IMPROVISATION IN TRANSITIONS[25]

The previous chapter developed a conceptualization of everyday practices with technologies in transitions for the discipline of design research. This chapter traverses disciplinary boundaries, and picks up the developed conceptualization for an expedition in the discipline of transitions research. We introduce the conceptualization and connect it to dynamics of transitions, specifically the Dutch heating transition, addressing research question 1. Next, we add a further layer of analysis to the ethnographic study reported in the previous chapter. For transitions research, this chapter advances an understanding of what is *required* in terms of *practice reconfigurations* that enable heat pumps to be taken up in a particular context. It also highlights the *innovative* potential of these reconfigurations when they have an impact beyond the household. We also identify how necessary and promising practice reconfigurations could be supported in technology development and policy in transitions.

In the context of this dissertation, this expedition in transitions research returns several additions to the developed conceptualization. Continuing the idea of *practice reconfigurations* as a feature of the conceptualization, we distinguish changes in everyday practices in transitions as *reconfigurations of knowledge, material reconfigurations*, and *reconfigurations of routines*. This chapter also adds the *innovative potential* of these improvisations as forms of *design in the use phase*, contributing to societal transitions. Together, the contribution to transitions research, and the additions to the developed conceptualization, address research question 2.

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[25] The paper on which this chapter is based, has been published as: van Beek, E., Boess, S., Bozzon, A., & Giaccardi, E. (2024). Practice reconfigurations around heat pumps in and beyond Dutch households. *Environmental Innovation and Societal Transitions*. 10.1016/j.eist.2024.100903. To avoid redundancy, this chapter omits a description of the data collection reported in chapter 2. Other edits include minor changes for readability and consistency (referring to chapters, not papers; and a consistent use of *crises of routines*)

3.1. Introduction

It is no longer news that our ways of living must change in the face of climate crises. In the global North, however, the household seems to be a protected place where everyday life can and should continue on its steady path toward greater comfort and convenience (Shove, 2003). In this paradigm, more efficient, and smarter technologies, for example for indoor climate control, can be introduced; they can be 'fit and forgotten' (as Parrish et al. describe this paradigm (2021)) while simultaneously resolving our dependencies on fossil resources. In this chapter, we join a body of scholarship and media that questions this paradigm of continuity. We provide evidence of how everyday practices in the household are reconfigured as part of sustainability transitions, and ask whether and how these reconfigurations can be addressed as barriers or as innovations in the context of sustainability transitions.

New heating and other indoor climate control technologies are recognized as necessary for transitions towards a low-carbon and climate-resilient society (IEA, 2013). In the Netherlands, the heating of spaces and domestic hot water accounts for 81% of the total energy demand of residential buildings (IEA, 2020), and is therefore an attractive target for reduction. The large-scale introduction of heat pumps for residential buildings should reduce CO_2 emissions and save energy while providing comfortable indoor climate in homes (van Leeuwen et al., 2017). They replace the commonly used gas boiler systems (van der Bent et al., 2022). This transformation of indoor climate systems should help achieve the goal of an energy-neutral Dutch residential building stock by 2050 (Tigchelaar et al., 2019). However, as of now, Dutch heat pump uptake lags behind the projected trajectory, and the spread of heat pump use is slow, especially compared to other countries in the EU (Toleikyte et al., 2023).

Heat pumps end up in households. The transition towards sustainable heating is a sociotechnical transition. It includes not only the technical dimension of implementing heat pumps, but also changes to other domains and infrastructures (Boess, 2022; Markard et al., 2012; A. Smith et al., 2005). The field of transition studies has recognized that households are crucial in these transitions (Raven et al., 2021). In relation to heat pumps, for example, the motivations and social and informational needs in the decision to acquire sustainable technologies are extensively studied (Ebrahimigharehbaghi et al., 2019). Households (as users of technologies) are also increasingly seen as sources of innovation, modification, and redesign of technologies and other solutions (Ornetzeder & Rohracher, 2006). Meanwhile, in the literature on sustainable technologies, household interactions (or 'occupant behaviors') tend to be considered a threat to the energy efficiency of buildings with sustainable technology (Caird et al., 2012; Roy & Caird, 2013). Unexpected behaviors of residents might contribute to a performance gap between predicted and actual energy consumption, and thus reduce the success of heat pump transitions (Guerra-Santin, 2013; Pettersen et al., 2017).

Increasingly, practice theoretical approaches are employed to better understand the relevance and roles of households in sustainability transitions (Svennevik, 2022). Such work has identified the introduction of heat pumps into households as 'processes of local reinvention' (Jalas et al., 2017). When a heat pump enters the household, practices of heating, cooling, and many other interlinked practices are disrupted and reconfigured. In this chapter, we adopt a view of everyday practices as a primary site of change in transitions (Warde, 2005), in this case: the heat pump transition in the Netherlands. This means that (1) we study changes (or 'reconfigurations' as we will come to describe these changes) of household practices around heat pumps to understand what is required to successfully incorporate them in everyday life, and (2) consider these reconfigurations as potentially innovative. These reconfigurations might need support to further the Dutch heat pump transition, but they might also present novel solutions to challenges encountered in everyday practices with technologies. In the present study we complement practice theoretical commitments with concepts from practice-oriented design research (Pettersen, 2015; Scott et al., 2012) to discuss practice disruptions and reconfigurations, the role of innovation and transitions (Jalas et al., 2017).

We ask the following questions: (1) How does practice theory help us see required practice reconfigurations around heat pumps, and the innovative potential of these reconfigurations? (2) Which reconfigurations can be observed when heat pumps enter Dutch households and what is the innovative potential of these reconfigurations in impacting sustainability transitions? (3) How do these reconfigurations currently interact with the Dutch heat pump transition, what hinders the required reconfigurations, and to what extent is their innovative potential realized?

We answer these questions by, first, introducing concepts and approaches from practice theory and practice-oriented design research. Secondly, we report on an ethnographic investigation into the introduction of heat pumps in 11 Dutch households. And third, we discuss how the ethnographically observed dynamics relate to larger-scale heat pump transition dynamics, and to practices outside the household. This study was conducted with an orientation to design, and as part of a larger design research project. Design research approaches have been highlighted for their potential contributions to transitions research (Wiegmann et al., 2023). Design research is an approach to gathering knowledge driven by field problems (in our case: the observation that heat pumps and associated technologies were not being used in the intended manner, in particular when existing buildings were retrofitted with heat pumps (van Beek & Boess, 2022)). Typically, in design research, knowledge is gained through an iterative process that involves evaluating implemented solutions and proposing improvements. In line with this approach, the present study aimed to identify areas where technology and processes in heat pump design and installation retrofitting could be improved.

Answering the questions posed above is valuable for studies on sustainability transitions as it can help to address a gap in our understanding of the role of households and in particular the ways in which household practices change as part of and in response to sustainability transitions (Raven et al., 2021). Such an understanding can foster and accelerate changes in sustainability transitions at the level of households, as consumers of resources, as users of sustainable technologies, and as sources of innovation. Specifically, for the Dutch energy transition context, answering these questions contributes to the potential success of the introduction of heat pumps, as this success depends on how they become embedded in household practices (Eon et al., 2017; Korsnes et al., 2018). Households also have the ability to innovate and contribute new solutions (Jalas et al., 2017). Engaging with these questions also further expands our understanding of the role of design decisions and interventions in transitions, and thereby to the ongoing alignment between studies of transitions and design (Gaziulusoy & Öztekin, 2019; Loorbach, 2022). Besides developing a design-inspired understanding of household dynamics, answering these questions also helps designers. They can target the evaluation and improvements of interventions more specifically towards transition goals, which makes answering these questions also valuable to the field of design research.

The remainder of this chapter is structured as follows: We first introduce the context by providing an overview of the relevant features of heat pump systems, and their role within the Dutch energy transition (§3.2.). We then discuss existing work that has investigated the relevance of the household and the introduction of new technologies in the household (§3.3.). We explain how concepts from practice theory and practice-oriented design research inform our understanding of these household dynamics (§3.4.). Informed by this framework, we report additional findings from the ethnographic study of 11 households with a heat pump (§3.5.); we discuss these findings against existing literature, and highlight implications for technology development and design, as well as for policy and research (§3.6. and §3.7).

3.2. A brief introduction to heat pumps in the Dutch energy transition

3.2.1. Features of heat pumps relevant to households in the Netherlands

A heat pump boosts low-temperature heat in the ground, air, or water to temperatures suitable for heating a building and/or domestic hot water (Roy & Caird, 2013). The energy (in the form of heat) that is transferred to the house can be up to four times higher than the energy (in the form of electricity) required to run the pump (a metric known as the Coefficient of Performance (COP)).

The current Dutch building stock is largely fitted with gas-fired condensing boiler systems which heat both domestic hot water and the water flowing through radiators emitting heat in every room (Kieft et al., 2021). While these gas-fired condensing boilers heat water to a temperature between 55°C and 85°C, heat pumps offer a different approach to domestic heating, as they normally produce heat at much lower temperatures (below 45°C). Heat pumps operate most effectively in well-insulated buildings with larger low-temperature heat emitters, preferably under-floor heating or convector radiators, which heat indoor air slowly and evenly, rather than quickly. Sometimes, additional fans are placed within convectors in the rooms that move hot air through the spaces more quickly, providing thermal comfort to the occupants without the need for high supply temperatures. In a building with an air-tight insulated outer shell, consideration of building ventilation becomes increasingly important to ensure healthy indoor air quality

(Balvers et al., 2008). The adequate performance of mechanical ventilation systems requires regular cleaning and exchange of air filters.

Finally, a relevant feature of most heat pumps is their limited capacity to produce domestic hot water. Systems deal with this by heating the hot water slowly (often during the night) to 55°C and storing it in a storage tank until needed. Typical storage tanks have a capacity of 100-200L. A 2008 study in the UK found that the mean domestic hot water consumption per household is 122 liters a day (Measurement of Domestic Hot Water Consumption in Dwellings, 2008).

The above factors are listed to indicate how heat pumps interact with household dynamics, and to show that the features of a heat pump require many other changes to the technological composition of the household (bringing with them 'smart home' features like automated ventilation and scheduled hot water production).

3.2.2. Heat pumps in the Dutch energy transition

Like in many other European countries, heat pumps are considered a key factor in improving the energy performance of housing in the Netherlands, contributing to less energy use and more sustainable sources of domestic heating (Kieft et al., 2021). This transition is motivated by European policy, which sets requirements for decarbonization to member states, as well as an interest in moving away from natural gas as an energy source due to ending exploitation of a gas field in the north of the country, and the reduction of natural gas import from Russia following the war in Ukraine.

According to a report from the European Commission's Joint Research Centre, the Dutch demand for heat pumps increased significantly in 2022, but the market is still small (Toleikyte et al., 2023). By the end of 2023, only 7% of owner-occupied single-family households had a heat pump (Kloosterman et al., 2023). Although, as the authors note, this number is likely to be an underestimation, there is still a striking difference with other European member states like Finland where 74% of detached houses had one or several heat pumps installed by the end of 2022 (Hyysalo & Juntunen, 2024). This difference has been explained with reference to low prices of gas, compared to electricity prices in the Netherlands (making gas-based boiler systems financially equally or more attractive) (Hyysalo, 2021, p. 144). Such economic motivations are also likely the explanation behind the market increase in 2022, following rising gas prices. Next to differences in energy prices, existing research has focused on technological innovation systems to explain what is holding back the Dutch heat pump transition (Kieft et al., 2021). In this chapter, however, we focus on the household.

Policy in this transition targeting households primarily focuses on them as consumers doing energy-efficient renovations and acquiring technologies such as heat pumps (Broers et al., 2019; Ebrahimigharehbaghi et al., 2019). Policy measures typically target building standards for new buildings, further subsidies for energy-efficient technologies, or taxes on energy carriers (Boonekamp, 2007).

There is an increasing awareness that, beyond this initial purchase decision, the use phase is critical, as energy-saving measures do not always have the intended result in terms of energy performance. However, post-occupancy evaluation of energy performance in buildings is rare. When it happens, it has been found that energy labels do not accurately reflect actual energy use in Dutch households (Majcen et al., 2013; van der Bent et al., 2022), a phenomenon also described as the performance gap. Currently, the observation of this performance gap has not resulted in coherent and targeted policy measures. In short, it appears that, in the Dutch heat pump transition, households are primarily approached as a closed box (Raven et al., 2021), they are considered as decision makers and resource consumers, without much attention to their internal dynamics.

3.3. Related work: Introducing new technologies in the household and sustainability transitions

In this section, we give a brief overview of related work on the relationship between sustainability transitions and the introduction of technologies into households. We focus on 'open-box' conceptualizations of the household, which means that they address household dynamics (Raven et al., 2021). We then summarize some literature that specifically addresses the introduction of heat pumps and household dynamics.

3.3.1. Introducing new technologies in the household as part of transitions

It has long been recognized that the introduction of new sustainable technologies in the household has consequences for everyday domestic life. Domestic routines and meanings change when new technologies are introduced in the household (Gram-Hanssen, 2008). Concepts like 'domestication' or 'appropriation' describe how material and non-material aspects (such as daily routines) shape one another (Aiesha, 2016; Aune, 2007). Researchers pay attention to the "construction of micro-networks" of humans, knowledge, practices, and things (such as technical devices) (Aune, 2007). Applying this concept of domestication, studies of smart home technologies, for example, found that these technologies are both technically and socially disruptive (rather than continuous and smooth) and require adaptation and familiarization from householders (Hargreaves et al., 2018). Other studies noted that the dynamics between household members are relevant to how sustainable technologies become domesticated (Skjølsvold et al., 2018). Different household members are asymmetrically involved in domestication (Juntunen, 2012), sometimes leading to conflicts. Other studies found that households' understanding of everyday life changes when interacting with new technology (Korsnes et al., 2018), and that they become skilled practitioners in the use of new technologies, but that these skills need to develop over time (Gunn & Clausen, 2013).

This dynamic relationship between households and the technologies introduced can have innovative outcomes when users tinker with new technologies (Ornetzeder & Rohracher, 2006), engage in experimentation (Jalas et al., 2017), and invent useful adaptations (Hyysalo et al., 2013). These studies more explicitly link local domestication processes to sustainability transitions by emphasizing bottom-up innovation. However, these studies are almost exclusively concerned with the outcomes and their innovative character. The more detailed level of internal household practices and how they change appears underexplored.

3.3.2. Introduction of heat pumps in the household as part of transitions

The specific features of heat pumps (as presented in section 2) have implications for household dynamics. Early research (Wrapson & Devine-Wright, 2014) from the UK found that early adopter households often use a mix of heating technologies, requiring 'juggling'. Similarly, a 2012 Finnish study (Juntunen, 2012) found that early adopters have a strong trial or experiment attitude. In addition, a recent overview (Hyysalo, 2021, p. 107) mentions reports of Finnish users adapting to heat pumps by keeping room doors open, changing furniture layout, or changing routines related to emptying iced-up meltwater from the heat pump. Judson et al. (2015) interviewed older tenants in English social housing that had been retrofitted with air-to-water heat pumps and found a strong legacy of existing systems, which impacts how residents experience and interact with air-source-to-water heat pumps. Additionally, residents became dependent on a new constellation of providers, such as social landlords and utility companies when the system did not perform as expected. Nyborg (2015) observed inventive uses such as Danish households' ability to modify a relay in a heat pump to shut the heat pump down completely at night. Hyysalo et al. (2013) described inventions that users made to their heat pumps and other heating technologies. The users significantly improved these technologies to match their specific situation and shared their innovations through internet forums. The authors accord this experimentation and innovation a role in sustainability transitions (Hyysalo, 2021; Jalas et al., 2017). An extensive study of user activities in the generalization of technologies found that there are a range of activities that have facilitated the spread of heat pumps in Finland (Hyysalo & Juntunen, 2024). These activities include not just changes to daily habits, but alterations to the equipment of their social and technical context.

In this more specific literature, we again notice an understanding of the difficulties of adapting to heat pumps, as well as an appreciation of the inventiveness and resourcefulness of households. However, this research is focused on other (non-Dutch) contexts. Heating practices significantly differ between (European) cultures (Sovacool et al., 2021), which means that the Dutch heating transition is likely to have different dynamics. These studies also do not address how local adaptations and resulting innovations relate to one another.

3.4. Reconfigurations in practice

Studies looking at the introduction of new technologies in the household often draw on theories of practice. These theories emphasize that material arrangements (such as new technologies) reconfigure practical understandings, meanings, and conventions, and thus influence how practices are performed (Shove & Walker, 2010). These reconfigurations are the focus of the present study.

Theories of practice (increasingly present in transitions literature) have also found some traction in the field of design and design research (Ingram et al., 2007; Kuijer, 2018; Pettersen, 2015; Shove et al., 2007) and the adjacent field of human-computer interaction ('HCI') (Kuijer & Giaccardi, 2018; Pierce et al., 2013). This adaptation of practice theory to design has been loosely grouped under the title *practice-oriented design research* (Jalas et al., 2017; Pettersen, 2015). Here, the practice theoretical framework is adapted to study everyday practices in detail and discover ways to influence these practices through design processes and designed interventions.

In this research, we adopt a practice theoretical lens to understand how household dynamics change with heat pumps. In our design-oriented approach, we pay specific attention to ideas from practice-oriented design research. First, practice-oriented design research assumes that individuals practicing everyday life are creative in their adaptation to new situations (Shove et al., 2007). This makes designers collaborators in redesigning everyday practices, rather than authors of new solutions (Botero & Hyysalo, 2013; Scott et al., 2012). We adopt this stance in the context of sustainability transitions by paying explicit attention to creative and unexpected (or 'un-designed') solutions in everyday practices. Second, practice theory pays explicit attention to the situatedness and history of practices. Any new practice or change in practices has its roots in existing practices which are newly linked or reconfigured (Kuijer, 2014). We adopt this notion in the context of transitions research by analyzing new household dynamics with an explicit reference to previous practices. Third, as contributed to in the previous chapter, design research (particularly HCI) has extended the practice theoretical framework to include the participation of technologies in practices (Kuijer, 2019; Kuijer & Giaccardi, 2018). This constitutes the lens we adopt here. Through a lens of co-performance, automated or 'smart' technologies participate in practices, not just as material elements but as performers that take on tasks (such as regulating indoor temperature or observing the weather) previously performed by humans. We use this lens to highlight how practices are delegated from humans to technologies (heat pumps and other technologies) and vice versa, and how this affects sustainable outcomes.

With this lens in place, we outline some more specific concepts (practice reconfigurations, everyday crises of routine, and innovations-in-waiting) that we will use in the rest of this chapter.

By *practice reconfigurations*, we mean any change in practices (Shove et al., 2012). Following our interest in (changes on) the meso-level of household dynamics (Raven et al., 2021), we focus only on (reconfigured) performances of practices within specific households, and not on practices at a societal level. Changes can occur in internal practice elements (e.g., order of action, or participating practitioners) or in the way they connect with other practices (e.g., which other practices they make possible). We elaborate further below how practice reconfigurations typically solve something for practitioners in everyday life. They make the practice more appropriate to the local context ('to make it work and make sense') (Kuijer & Giaccardi, 2018). This does not necessarily mean that these reconfigurations are beneficial towards transition goals (such as conserving energy, or diffusion of sustainable technologies). They might be neutral, positive, or negative.

Reckwitz (2002) describes *everyday crises of routine* as "constellations of interpretative indeterminacy". The concept refers to situations where a practice is disrupted, established ways of doing things are de-routinized, people do not know how to go on, which leads to a "crisis of routine" (Shove et al., 2007, p. 34). Such a crisis can be a minor inconvenience in daily life which is then quickly resolved (by reconfiguring practices) or a more serious barrier to the continuation of routines. When applied to material arrangements (such as the implementation of heat pumps), such disruptions can be seen as a consequence of the introduction of new technologies (Shove et al., 2007, p. 34), for example at the moment of handover (Behar, 2016). These disruptions (and everyday crises of routine) form starting points for new practices and might be interesting, and perhaps even necessary, situations in moving towards sustainable practices (Kuijer et al., 2013; Viaene et al., 2021).

When such a crisis of routine occurs, people generally figure out a way to go on. They improvise and invent a new practice on the spot. These reconfigurations can be considered to be "*innovations-in-waiting*", or 'proto-practices' (Shove & Pantzar, 2005, p. 48). The innovations are not yet fully realized as they are not integrated into fully formed practices. In practice-oriented design research, proto-practices or innovations-in-waiting are not seen as stopgap solutions for a difficult situation, but rather as an opportunity for the formation of desirable (more contextually appropriate or more sustainable) future practices (Kuijer et al., 2013). These innovations-in-waiting could be repeated and diffused in other ways beyond this specific situation. We therefore pay attention to such potential occurrences.

3.5. Methods: An additional layer to ethnographic analysis

Our empirical study adds another layer to the previously reported ethnographic investigation. In the context of this chapter, it is relevant to identify some characteristics of the participating eleven Dutch households (figure 3.1.). Each of these households has, within the past six years, begun living with heat pumps. Nine of these households were renters and were invited to participate through contacts at social housing and rental organizations. Two were owner-occupied and were recruited through word-of-mouth in the researchers' social environment. The sample balances older and younger people, couples, families, and single dwellers. The buildings are both apartments and terraced houses. The sample of participants and building characteristics is diverse and reflects the Dutch context.

Locations A and B in table 2.1. (see chapter 2) are characterized as different experimental 'living lab' settings (Keyson et al., 2017) where stakeholders test new and sustainable technologies in inhabited environments. This makes them particularly interesting to be included in this study: innovative reconfigurations might occur in these settings. The six households listed first in table 2.1 are part of a set of newly built homes located in the North of the Netherlands (location A). A social housing organization commissioned these buildings as zero-energy buildings to test several smart home technologies in social housing. Features like sun shading, indoor lights, and thermostats are automated, and can be controlled and monitored by an external home automation technology company. The three households listed at the bottom of table 2.1 are recently built homes located in the South-West of the Netherlands (location B). They are realized as part of an effort of researchers and technical companies to investigate the potential of new sustainable technologies. The terraced houses in location B are replicated common Dutch 1970s residential buildings specially built to investigate retrofit possibilities. The buildings and technology performances in location B are monitored by researchers who collect, e.g., energy consumption data and heat pump performance numbers and administer quantitative indoor comfort surveys.

Figure 3.1. Technical features in the participating households (Left to right, top to bottom: an air-to-water heat pump, air filters being replaced, a display showing domestic hot water consumption and budget, low-temperature heating convectors)

3.5.1. Data analysis

As reported in the previous chapter, already during the interviews, the topic of reconfigurations was discussed, specifically by asking how practices had changed, what participants found challenging about living with the new technologies, as well as through focused and contextual follow-up questions that arose. In the analysis phase, we identified reconfigurations by looking for instances where participants described situations or their experiences as exceptional, non-standard, non-routine, or non-mainstream. Additionally, for the context of this chapter, innovations-in-waiting were identified by looking for new practices, invented in response to these challenges. We also took note of instances where participants expressed uncertainty or where we ourselves felt that the situations or experiences were non-standard.

3.6. Findings: Practice reconfigurations

We found three types of reconfigurations in the households following the introduction of a heat pump. The three types are: reconfigurations of understandings (§3.6.1.), material reconfigurations (§3.6.2.), and reconfigurations in routines (§3.6.3.). In §3.6.1.-§3.6.3., after each description of instances of reconfigurations, we highlight and speculate on how they have an impact in the household beyond the specific instance. We also evaluate whether these reconfigurations seem desirable in the light of sustainable transition goals. The impact of a reconfiguration might be its reproduction elsewhere ('the recruitment of other practitioners' (Shove et al., 2012, p. 70)). The impact might also be in other ways in which practices link together and thereby impact one another. In §6.4, we widen the perspective and indicate how observed reconfigurations impact relations with other households and professionals. We group our findings in a similar way as previous work has done (Skjølsvold et al., 2017). As will be shown in the findings, the three types of reconfigurations are intertwined and associated, but each grouping highlights an area of impact.

The findings highlight reconfigurations (and thereby emphasize change) and should not be read as a comprehensive record of all types of household interaction with heat pumps. One of our participants, Bas, for example, told us: *"Everything is the same, except that the heat is made differently."* Our specific focus on reconfigurations means that continued practices and less dynamic situations are not included in what follows.

3.6.1. Reconfigurations of understandings

The introduction of a heat pump requires and allows for reconfigurations of knowledge and competences in dealing with indoor climate and technologies.

Newly developed understandings

Rudolph explains how the slow and gradual heating from the low-temperature heat pump means that the family needs to think more about their short-term future needs in everyday life. *"If you know that you will be sitting still in the evening, you have to start thinking about that at five. And put it up, then it will be warm by eight."* Other examples from our data indicate that households became sensitized to features of the heat pump affecting everyday practices. Gemma became aware of her household's hot water consumption from frequently being confronted with the limits of the domestic hot water production of the heat pump. *"And then we started paying closer attention. (…) "So doing the dishes also counts. (…) We have to make some calculations."*

New local knowledge through experimentation

Rudolph and Alice experiment with the building they live in. They left the bedroom windows open for one night, documented and compared the temperatures as shown on their alarm clocks in the evening and the morning, and found that the open windows indeed make a difference. Alice: *"It only made a difference of one degree."* Rudolph: *"Yes, but the heat pump has to pump to keep it at that temperature."* The family gained a new understanding of the effects of open windows and how this relates to heat pump performance. This type of reconfiguration of competences is anchored in experimentation and tinkering as also found by Skjølsvold et al. (2017). While this experiment initially increases energy consumption, this reconfiguration of knowledge can also contribute to sustainable practices by preventing future unnecessary window openings, while retaining window opening when this is appropriate (e.g., summer nights when the heat pump will not become active). The successful integration of such an experiment in regular practices may depend on confirmation that the reasoning is right – and this could be supported by affirming feedback from technology developers.

In another household, Laura discovered a way to know when the underfloor heating is on. Laura explains how the dog in their household starts panting due to warmth from the underfloor heating. This crisis in (the pets') routines led the dog to lie on the couch in winter, rather than on the floor, since he finds the heated floor to be uncomfortable. This newly acquired understanding could potentially lead Laura to a more conservative use of the underfloor heating, leaving it off when not required and when the dog finds it uncomfortable. Multiple households in our research referred to their pets' behavior as helping them understand the operation of the underfloor heating. However, it is unclear how these competences could transfer to other situations and households (without pets).

Broader impacts of reconfigurations of understandings

These examples illustrate that the introduction of a heat pump required residents to develop new knowledge, and how this change enabled a reconfiguration of competences and knowledge. A typical feature of these reconfigurations is that they are developed experimentally and are driven by unresolved challenges in everyday life. This theme highlights how new configurations of competences both facilitate and are required for technologies to be taken up in everyday practices. While these experiments might have initial adverse effects (consuming more energy), they could lead to energy savings in the long run. The question remains if the thus acquired knowledge is correct, and how such local competences could transfer beyond the boundaries of the household.

3.6.2. *Material reconfigurations*

The introduction of a heat pump is itself a reconfiguration of the material setting. Following the specific introduction moment, the presence of a heat pump also caters to other rearrangements of material environments. We identify these in this theme.

Material reconfigurations that resolve heat pump inconveniences

The introduction of the heat pump introduced inconveniences in the household that the residents did not have to deal with before. Several participants in our research explain how they modified the material setting to resolve these inconveniences. Alice and Rudolph, for example, recount with pride how they had previously adapted the top floor to a room for their son to sleep and work. However, the ventilation system is also located here. "*But this system makes a lot of noise. So, we put in a lot of sound insulation."* This material reconfiguration resolved this crisis in their routines (figure 3.2.). Louise explains how she has been instructed to keep the polyvinyl flooring, which she does not like, to make sure the underfloor heating performs well. *"I think it is too hard."* She has covered the floor with a rug in the main seating area to resolve this issue (figure 3.3.) and explains how she is still busy with wall decorations to 'soften the room'. Alice and Rudolph again talk about their son working from home on the top floor of the house. *"He likes the holiday temperatures, you know. 25, 26 (*degrees Celsius*)"* These higher temperatures cannot be provided by the low-temperature heat pump and delivery system. Instead, the family has installed an additional electric heater on this floor.

Figure 3.2. Rudolph shows the sound insulation that reduces the noise from the ventilation system

Figure 3.3. Louise's rug that softens the room

In some cases, material settings were reconfigured as part of attempts to compensate for technical inefficiencies and optimize performance. Sebastian has installed a backup system to compensate for and counter some of the problems with the heat pump performance: *"Yeah, I have a backup 3kW heater. I installed it as an experiment to see if I could effectively reduce the defrost effect and increase the overall COP* [Coefficient of Performance, a measure of heat pump efficiency]. *(…) In any case, it gives some peace of mind for extreme winters."* Since Sebastian is active in online forums where tips for improving heat pump performance are circulated, this local material reconfiguration also reconfigures others' understandings and has a further impact beyond the specific situation.

Material reconfigurations taking advantage of technical features

The introduction of a heat pump and a better ventilation system in the household allowed participants in our research to take advantage of the systems' features in surprising ways. Julia and Mick combined a portable dehumidifier they already had with the stable temperature and humidity in their new house and in such a way created a room for drying clothes. *"Our previous house was very humid, so we had a dehumidifier. Now we turn it on, we just close the doors, and in two hours it's perfectly dry."* A similar resourceful way of drying clothes was found elsewhere. As the heat pump emits heat with low water temperatures, the buildings in location A have an additional electric radiator in the bathroom for some additional comfort. Many participants mentioned that they never turn on this radiator. However, Laura explains how she takes advantage of this radiator. *"We don't have a clothes dryer, I don't need that, once in a while I put pants on this [the heater] and then it dries very quickly."*

Broader impacts of material reconfigurations

These examples illustrate how the introduction of a heat pump leads to a reconfiguration of material settings. They illuminate how practices (e.g., heating, washing clothes, etc.) are closely interwoven, and are thus not easy to change. Residents applied reconfigurations to resolve inconveniences, continue household everyday life as before, improve on system performance, or take advantage of system features. These reconfigurations were often resourceful (Kuijer et al., 2017): the residents made efficient and creative use of the resources (for example: dehumidifiers) available to them. We found reconfigurations that were not yet aligned with transition goals and consuming more energy, such as additional heaters. We also found reconfigurations that enable more sustainable practices. For example, using the electric radiator to occasionally dry clothes reduced the potential need to buy a tumble dryer, which might quickly be used more often. Thus, such local reconfigurations hold the potential for households to live more sustainably, to overcome obstacles, and to integrate the heat pump into everyday life.

3.6.3. Reconfigurations of routines

Beyond the expected routines required for making the heat pump work (such as turning up the thermostat when it gets cold), we found other reconfigurations of routines. We observed how they relate to previous arrangements of routines, and how they might be new or shared.

Existing routines repurposed, old routines becoming obsolete, and gradual reconfigurations

Participants explained how their routines were slowly reconfigured in response to the changed conditions in the home. Gemma used to live in a poorly insulated home with inadequate heating where the family wore shoes and thick jumpers inside the house. That has changed: "*I really shouldn't walk in a thick jumper around the house. That'll get me way too hot.*" Now, she is trying to implement a new household rule to not wear shoes inside, to save her cleaning time. Here, the reconfiguration in comfort practices clearly impacts other practices, like cleaning. This reconfiguration might thus realize beneficial, if small, effects on energy consumption.

Julia explains a similar gradual reconfiguration of routines. As their previous house was much less insulated, Julia and Mick had a routine of wearing multiple layers of clothes and keeping the thermostat low to reduce energy consumption. Julia indicates how a material configuration still caters to a routine from their previous house: the couch still has a *"big fluffy blanket"*. Maintaining the routine of using this blanket allows them to still keep the thermostat low and not have to turn it up for a more sedentary evening activity during which one is likely to feel more need for warmth.

Participants also explained how reconfigurations in routines were slowly optimized to become appropriate to energy efficiency. Ella has been advised to keep the windows and doors of her apartment closed when the heating is on. However, since she has cats, she likes them to hang out on the balcony, but still walk in and out. She finds a balance, by opening the balcony doors slightly in the morning, just enough for the cats to pass through, while not letting too much cold air in (figure 3.4.).

Figure 3.4. An opening in a door that is just wide enough to allow a cat to pass through, without losing too much heat.

Broader impact of routine configurations

Like material reconfigurations, reconfigurations in routines are ways to resolve crises of routines, mainly motivated by continuing household everyday life as it was before the introduction of a heat pump. Routines tend to change slowly and might persist even though the situation that prompted them to develop has disappeared. The examples above indicate routines (like sitting under fluffy blankets) which find new purpose in new situations. This reveals both the rigidity of practices that do not immediately adapt to new technologies such as heat pumps, and the cross-fertilization of practices (Warde, 2005). The latter enables appropriate reconfigurations ('that work and make sense') to be applied elsewhere.

3.6.4. *Reconfigurations impacting practices beyond the household*

In this section, we describe our observations of the ways in which reconfigurations impact practices beyond the boundaries of the household. These observations suggest potential routes for innovations-in-waiting to have a broader impact and become applied or established innovations.

Impacting other households

Reconfigurations in practice were found to have an impact beyond the household when a resident's technological or household expertise was applied outside of the home. Rudolph, for example, appeared to play a leading role in making his optimizing reconfigurations known to neighbors. He demonstrates in his own household how the domestic hot water budget can be increased by changing a setting. *"If you read the manuals, you can change it from economic to comfort setting. And most people don't know that."* This setting made the boiler heat the domestic hot water more frequently, and thus gave the family enough hot water during the day, instead of occasionally ending up with a cold shower. Rudolph then explained how he had applied the same setting to Louise's system and suggested it to other families in the neighborhood. *"You have to turn off the economy setting, especially with four kids."* Ella, another participant in our research, has also received advice from him. She explains how she trusts the technical expertise of one of her neighbors in the same building to help her reprogram the thermostat which she struggles to understand (figure 3.5.).

Figure 3.5. Ella's interactions with the thermostat

Another way reconfigurations have effects beyond the household is through observable norms. This becomes clear in a conversation between Alice and Rudolph during our visit. Alice likes to open up the windows for fresh air. But Rudolph thinks that this is unlikely to help. *"It is (already) well-ventilated, but that's something you don't understand."* Alice responds: *"No, I don't like the feeling of it."* Alice then supports her claim that open windows are an appropriate practice by pointing out that many neighbors do the same. *"I see a lot of windows open in the neighborhood."*

Herbert is enthusiastic about the novelty of his house, which is visible from the outside and known to other town residents: *"When I'm doing gardening in front of the house, people ask for information. That has already happened four or five times. (…) I can only tell (them) that we don't have gas, and that electricity generation happens during the day."* Here, the dwelling's 'living lab' character enables impact beyond the household and might incentivize other town residents to implement similar measures.

More technical and experimental reconfigurations were also found to impact other households. Sebastian is active on an online forum with other owners of this specific model of heat pumps. He is currently waiting to receive a printed circuit board (PCB) that another forum member is developing, which will regulate the heat pump performance in ways that will reduce defrosting effects. This, in the end, should reduce costs and environmental impact.

In summary, we found that reconfigurations within households impact other households by being observable and thereby normalized, and by sharing competences and information with neighbors. In addition, even specific material reconfigurations (such as modifying heat pump performance with a controller PCB) can be shared beyond the household (notably: without a role for professionals). This last case also highlights the role of digitally mediated communities in the impact of innovations, as also reported in the Finnish context by Hyysalo et al. (2021; 2013). Another relevant observation from this data is that the reconfigurations reported here reproduce (rather than innovate on) traditional configurations of gender and technology, contrasting perceived as masculine technological explanations against perceived as feminine social knowledge (de Wilde, 2020; Oudshoorn et al., 2004).

Impacting professional practices

In addition to their 'horizontal' impact on other households, reconfigurations also 'vertically' impact professional practices. Louise for example, recalls how there seemed to be a fault in the heat pump system in her home, and different technicians visited repeatedly for repair. In conversation with a technician, she has temporarily set the thermostat to 24°C. Then the technician has rerouted some piping, after which the room finally gets warm enough. She has taken photos of the thermostat as documentation and proof of these settings. This experimental reconfiguration (setting the thermostat to 24) is closely connected with professional practices and impacts future installation decisions by technicians.

In a similar response to inadequate system performance, Ella has made a temporary material reconfiguration. In her bathroom, the underfloor heating does not heat the room adequately. She has used a thermometer to determine how hot the room can get. Now, she has marked on the bathroom floor (figure 3.6.) where it gets warm and where it does not. She intends to call on the installers of the heat pump to repair the problem by installing a new radiator, connected to the underfloor heating.

Figure 3.6. Ella's bathroom floor markings indicate where the floor gets warm and where it does not.

Figure 3.7. Gideon shows the dust that settles on the air filters.

During the research period, the building contractor is constructing similar houses across the street. Gideon explains how reconfigurations in his household are closely connected with the professional practices there. Gideon has shared with the building professionals how the air filters in the ventilation system have quickly become black (figure 3.7.). In this way, together with the contractor, they found out that the dust from the building site settles on the air filters. This information has led the maintenance company to distribute air filters more frequently during the time of construction, thus impacting professional practices.

In summary, reconfigurations happening in the home are both embedded in, and triggered by professional practices. Professional and local household expertise come together to shape these 'innovations-in-waiting'.

3.7. Discussion and implications

Heat pumps are expected to play a key role in sustainability transitions in the Netherlands and beyond. The introduction of a heat pump has effects beyond simply replacing a material element (the heating technology): it reconfigures household practices. We have categorized changes in households as reconfigurations of understandings, material reconfigurations, and reconfigurations of routine. We have shown how these experimental reconfigurations or innovations-in-waiting (such as reasoned window opening) can have impacts both aligned with, and deviating from transition goals (i.e., reducing energy consumption). We also found that these reconfigurations have potential impacts beyond the household (e.g., by being observable by neighbors).

We used concepts from practice theory (such as reconfigurations) and practice-oriented design research (innovations-in-waiting) to study the introduction of heat pumps on the meso-level of households in transitions. The study has resulted in two aspects to highlight. First, we have highlighted that the required reconfigurations align heat pumps with existing household practices in the participating households. These reconfigurations represent potential barriers to heat pump adoption in the Netherlands, as practices are densely interwoven (e.g., heating and care for pets), and households might shy away from technologies requiring effort to integrate into their lives. Specific required reconfigurations are understandings (such as understanding how the heat pump works, and skills of planning ahead), material (such as noise insulation, additional heaters for colder areas or extra warmth needs), and routines (such as daily choices in clothing or door- and window opening). In the next section, we highlight some ways in which technology development and policy might respond to, support, or take away the required reconfigurations. Second, the study highlights how these reconfigurations hold the potential to both reduce everyday annoyances and, in some cases, decrease the environmental footprint of household practices. Our research demonstrates that the impact of innovative reconfigurations beyond the boundaries of the household is not realized straightforwardly or predictably. Innovations-in-waiting are not always positive toward transition goals, and they are vulnerable and in need of support (Keller et al., 2022).

The results showed that there is diversity in responses to crises (from adapting window opening routines to developing controller PCBs). We regard all these as local reinventions of technologies (Jalas et al., 2017), but there is a need to further unpack how these reconfigurations develop and relate to a diversity in citizen competences, and how they relate to innovations from other settings (e.g., off-the-shelf controller PCBs). We have also noted a diversity in households and among household members. Gender roles may have a role in shaping who is innovating and how. Some of the diversity in willingness and ability to innovate might be attributed to matters of ownership and control over the home. Renter households, for example, had few options to modify their home in a material sense, but their innovations-in-waiting seemed to have more impact beyond the household due to their involvement with a constellation of providers of energy, maintenance, etc. (Judson et al., 2015). Our results also showed an important role for neighborhoods in the impact of innovations-in-waiting. This can be attributed on one hand to close spatial and social proximity, but also to the similarity of technologies installed in these houses, which made innovations more directly applicable.

The understanding of reconfigurations detailed in this chapter aligns with earlier calls for 'opening-the-box' of the household (Raven et al., 2021). We have contributed to a view of households, not as receivers of a technology, but as creative actors giving technologies a place in everyday life. This view implies seeing heat pump innovation as a (non-linear) process, rather than a one-time purchase (Aune, 2007). Our view relates the internal dynamics of the household more closely with other scales and places (or interlinked practices in practice theoretical terms), in this case, most notably: the neighborhood, and professional practices of technology rollout in the Dutch energy transition. This is in contrast with current framings of the household within energy transition policy (which is often concerned with increasing technology uptake) and with current design and technology development practices (often focused on making sure technology is used in the 'right way'). Instead, our framing suggests a different site where transitions take place - the household - and thereby a different source of innovation. Households could be recognized, supported, and further studied as a resource in realizing the ambition of energy transitions in the Netherlands and elsewhere.

3.7.1. *Implications for policy*

Our findings suggest that besides the current policy focus on technology roll-out, policy could also target household practices (Spurling et al., 2013). The required practice reconfigurations (in understandings, material, and routines) required in the Netherlands could potentially be supported through policy interventions. Reconfigurations of understanding for example could be supported with policies promoting the distribution of information material or with campaigns of learning from innovations-in-waiting. Material reconfigurations could be made easier when heat pump replacement is considered to be part of integrated renovation (for example, replacing not just heat insulation, but also sound insulation). Reconfigurations of routines could be supported with dynamic electricity tariffs, making the performance of energy-intensive routines more attractive at certain times of the day. Future research could compare the dominant heating and heat pump-related practices (and thus the required practice reconfigurations) in the Netherlands with other contexts. In Nordic European countries, for example, heat pumps are more widespread (Hyysalo, 2021, p. 144). Comparisons with these contexts could reveal configurations of practices that have been found to be appropriate to home heating with heat pumps (e.g., stable indoor temperatures).

Supporting such reconfigurations is a necessary ingredient of policy and technological interventions. However, the design of such interventions should also account for the dynamics of transitions. Social practices, technology uptake, and the goals of societal transitions are all shifting targets. Likewise, supporting a heat pump transition in late-follower countries like the Netherlands will have to be different from the more minimal support required in the early phases of heat pump transitions in early-adopter countries like Finland. The consequence of this is that the necessary support for heat pumps will likely not be the same now as it will be in the future. When heat pumps become more accepted as normal heat generators, different measures will be required. The focus might shift towards convincing later adopters. Likewise, when transition goals shift from the diffusion of heat pumps to an overall reduction of energy use or to the optimization of demand patterns over time, different interventions are required again.

The understanding of everyday practice and innovation developed in this chapter also implies an active role for households in realizing the Dutch energy transition, as the sites where change happens. Existing research in the field of transition management has developed diverse strategies and approaches to enable and promote such bottom-up innovation. One might think of niche development where innovations are protected (Loorbach et al., 2017), promoting experimentation (Sengers et al., 2019) or sharing and amplifying innovations through policy (Vezzoli et al., 2008). More concretely, policy could support the dissemination of innovative reconfigurations through demonstration homes, guided tours around local houses with improvements, or even vocational courses to share expertise, as also suggested by Jalas et al. (2017).

Another potential avenue for policy measures lies in the further integration of the spheres of technology installation and energy provision, which incentivizes monitoring of what happens after installation. This is currently already experimented with in the Netherlands and elsewhere through energy performance contracting mechanisms (Guerra-Santin et al., 2022). This research confirmed an important role for professionals as intermediaries, which was also found in previous research on technology implementation (Behar, 2016). More innovative households and their innovations could be championed by intermediaries such as installers (Martiskainen & Kivimaa, 2018; Owen & Mitchell, 2015), energy coaches, and advisors who have an on-the-ground view of technology-household interactions (Bouzarovski et al., 2023) or by citizen initiatives such as the “Duurzame Huizen Route”, an annual open day for sustainable houses (*Duurzame Huizen Route*, n.d.).

As also observed in our data, living labs, or other 'out-of-the-ordinary' settings, can stimulate the willingness and acceptance of households to engage in experimental reconfigurations, while simultaneously making reconfigurations more visible. These living labs are sites where experimental governance, technical innovation, and the change of daily practices are all brought together to participate in the co-creation of new integrated solutions (Keyson et al., 2017; Liedtke et al., 2012). These living labs can also serve to monitor and evaluate experimental reconfigurations and their impact.

Other potential avenues for the dissemination of innovative practice reconfigurations benefit from social and spatial proximity and cohesion, such as in neighborhoods. These avenues can extend, or be combined with, community-based programs to retrofit (Karvonen, 2013). Such programs support (further) engagement between occupants, housing providers, community groups, local authorities, and construction professionals. They can be helpful in disseminating innovative practice reconfigurations, not only in the initial retrofit decision, but also in the later appropriation of the technologies. Similar supportive roles could be taken by energy communities or local energy co-operatives (Lode et al., 2022).

3.7.2. Implications for technology development and design

The findings from this research highlight how technology development and technology use are interrelated practices. This implies a change to the traditional model of new product development which rarely attends to what happens after launch (Ingram et al., 2007). We agree with previous research that innovation involves an iterative loop between design and use (Hyysalo, 2021; Khalid & Sunikka-Blank, 2020; Usenyuk-Kravchuk et al., 2022), a loop which, in our view, can be tightened. This broadens the scope of design from purely material elements such as technologies, to inter-household configurations of understandings, routines, and material settings. Jalas et al. (2017, p. 78) have championed practice-oriented design research for its potential to support local changes in practices in the context of transitions. Practice-oriented design research reorients design from a narrow focus on products and technologies (e.g., improving the efficiency of heat pumps), to practices (routinized ways of enacting everyday life). The role of designers is then to facilitate the local adaptation of, and to create a better fit with, new technologies by supporting the remodeling of everyday routines (Pettersen, 2015; Scott et al., 2012).

Our findings show that innovation is a collective accomplishment of both technologies (and their designers) and users. This means that creativity and authorship are (partially) relocated from professional design practices to everyday practices in the household (e.g., the repurposing of a dehumidifier). This invites designers to examine the characteristics of successful and desirable reconfigurations as potential solutions that could be implemented or supported elsewhere. Designers can contribute by surfacing, articulating, and supporting these potentially successful, or innovative alternatives (Botero & Hyysalo, 2013). A wide range of design tools is available for this (trigger products, low-fidelity prototypes, design of communication tools, etc.) (Giaccardi & Nicenboim, 2018; Kuijer, 2014).

Features of the technologies themselves could also have a role in supporting and enabling creativity in household practices (e.g., the possibility to connect a controller PCB to a heat pump). This echoes previous suggestions that reconfigurations (and thus the local appropriation of technologies) can be enabled by modular and ambiguous designs of technology (Boon et al., 2018; Usenyuk-Kravchuk et al., 2022). Such an approach could also stimulate a risk-taking attitude among end-users, leading to more innovative practices. We noticed that residents reflect on reconfigurations as a way to evaluate their appropriateness (or 'local adequacy' (Usenyuk-Kravchuk et al., 2022)) and sustainability. In this way, professionals could support innovative and successful reconfigurations by designing technologies that support reflection in practices (Backlund et al., 2006; Ghajargar et al., 2018).

Finally, professional design cannot be seen as separate from the society in which its resulting objects are used. What is a normal and appropriate way of living with technology is continually reconfigured by inventive users (as we have seen in this study). These reconfigurations in turn influence how and which products are developed and put on the market (de Laet & Mol, 2000; Usenyuk-Kravchuk et al., 2022). In other words, there is a recursive relation between design and use (Kuijer & Giaccardi, 2018). This observation suggests, first, a practice of design that is sensitive to diversity in product use (or misuse). Second, it suggests that this sensitivity can be improved by including the people "destined to use a system to play a critical role in designing it" (Schuler & Namioka, 1993). Third, this participation can be made more responsive when designers tinker and explore reconfigurations together with end-users (Scott et al., 2012).

3.8. Conclusions

This study set out to find out how everyday life in Dutch households is reconfigured when heat pumps are introduced and to consider the impact of these reconfigurations beyond the situations at hand. We found reconfigurations in understandings, material settings, and routines. We also found that these 'innovations-in-waiting' impact peer households and professional practices, and could do so even more. The findings have yielded implications for policy and technology development. The latter could embrace supporting the required reconfigurations in Dutch household practices and exploring the further potential for innovative practice reconfigurations to contribute to sustainability transitions. Our analysis is exploratory and based on a small number of participating households. The findings suggest future work on approaches that can uncover, spark, and diffuse further innovations-in-waiting.

4 EXPEDITION 2: RESPONSES TO IMPROVISATION[26]

Everyday practices with technologies in transitions are not only relevant to design and transitions research, as we have shown in the previous chapters. In chapter 3, we showed how the everyday practices of people with heat pumps have innovative potential. This means that designers and configurators of heat pumps (the supply side) could benefit from knowing about this, as it has the potential to impact how these technologies are developed, marketed and implemented, and their energy consumption in use. In this chapter, we traverse another disciplinary boundary, and venture into building sciences, a discipline that develops such knowledge, specifically in relation to heat pumps.

For the heat pump supply side, unintended use presents a challenge. This chapter introduces our conceptualization as an alternative view on unintended use, framing it as improvisation. We communicate this perspective in a sensitizing video using the analogy of theater performances. We carry out semi-structured interviews with professionals in the Dutch heat pump value network to examine their responses to improvisation and identify factors influencing the choice of response. For building science this chapter introduces improvisation, which sets the stage for a design process in collaboration with end-users that continues beyond delivery.

Together, the contribution to building sciences, and the additions to the developed conceptualization, address research question 2. For the conceptualization under development in this dissertation, this chapter adds the *analogy of performance*. We also identify *sites of intervention* for design, addressing research questions 3 and 4: socio-technical innovations that enable *responses to improvisation*, by bridging technology development and everyday practices.

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[26] This chapter is based on van Beek, E., Boess, S., Bozzon, A., & Giaccardi, E. (2025). 'Try this and see if it works for you': A new perspective on household improvisation and responses from heat pump supply-side actors. Energy and Buildings, 338, 115725. https://doi.org/10.1016/j.enbuild.2025.115725 Minor edits are made for readability and consistency.

4.1. Introduction

The building sector is responsible for approximately 36 % of the greenhouse gas emissions in the EU (European Commission, 2020). Therefore, the energy performance of the European housing stock is an important target for low-carbon transitions. Yet, as it stands, the rate and depth of renovations to increase this energy performance lags the required pace to reach climate goals. Heat pumps are important products within these renovations, specifically for the Dutch housing stock (van Leeuwen et al., 2017). Recent studies have started to investigate how heat pumps are taken up in everyday practices of residents and found that the use of heat pumps (termed 'occupant behavior') is often not as expected (Judson et al., 2015; van Beek et al., 2024; Winther & Wilhite, 2015). This discrepancy (between intended and unintended use) has been considered a contributing factor to the performance gap; a gap between predicted and actual energy use in renovated buildings (Guerra-Santin, 2013; Kazmi et al., 2022). This discrepancy also presents a challenge for the heat pump value chain (or 'supply side'), such as manufacturers, wholesalers and service partners, as it leads to uncertainty about actual energy savings. The uncertainty in turn affects the customers' willingness to invest in low carbon technologies such as heat pumps. We posit that a reason for the discrepancy between intended and unintended use is that the heat pump value chain at this moment remains largely disconnected from the everyday use of heat pumps post-installation (on the 'demand side). This prevents the value chain from learning from use and addressing unintended use. Connecting the heat pump value chain better with heat pump use can potentially speed up learning and improve the quality and rate of renovations.

This study explores the connection between the heat pump value chain and heat pump use. We study how actors in the heat pump value chain interact with use, particularly unintended use. To clarify, this study is not primarily about the technological aspects of heat pumps – although we offer some implications for heat pump design choices – but about a crucial gap in the value chain and how it could be addressed with innovation in the interaction between demand- and supply side actors.

We bring a specific perspective to the investigation: a perspective informed by current design research. In this perspective, unintended use is viewed as an opportunity to adapt to and collaborate with end-users. It positions use and design in a closer relation with each other. A key term we use in this is 'improvisation', to describe the ways in which residents' practices deviate from prescribed use, and all the other types of unintended use or unexpected occupant behaviors. We use the term 'response' to refer to the ways in which professional practitioners in the heat pump value chain engage with this improvisation.

We seek to answer the following questions: How do professional practices in the supply side of heat pumps respond to improvisation? This can be further split up into the following sub-questions: 1.) What is the current diversity in responses by professional practitioners to improvisation by end-users of heat pumps? 2.) Which factors determine the choice of response for professional practitioners? Having explored these questions, we then consider how our design research perspective highlights areas for innovation in the relations between supply side and use.

Understanding professional responses to improvisation sheds light on an area that has not been explored in depth: the relation between the supply side and the use of heat pumps. This study sheds new light on connections and relations between heat pump development and use. Understanding these connections can highlight areas for improvement in this relationship and inform socio-technical innovations (innovations that integrate social and technical perspectives (Lowe et al., 2008)). In this context, these innovations can enable (faster) learning by supply-side actors and other ways of productive engagements with unintended use (Boess, 2022). On a larger scale, such improvements are required to ensure that the transition to heat pumps is achievable and responsive to residents' activities, socio-economically feasible, and ultimately leads to reduced energy consumption on a national level. As such, this study aims to present a holistic view of renovations and heat pumps that integrate both the renovation themselves and the use phase.

We structure this paper as follows: we first briefly discuss the Dutch heat pump transition, the relevance of heat pump use, and the current gap between the supply side and the use situation. After explaining and grounding our design research perspective in literature, we discuss our methodology. We prepared interviews with relevant professional practitioners throughout the heat pump value network in the Netherlands. In preparation for these interviews, we produced a sensitizing video that communicates our perspective and the idea of improvisation by proposing several potential responses to improvisation. This video becomes a stimulus in the latter part of each respective interview. After describing the results from the interviews in ten responses and nine determining factors, we discuss our results with reference to literature and highlight how introducing our perspective in relation to interview data, suggests socio-technical innovations connecting supply side and use.

4.2. Background and related work

4.2.1. The Dutch heat pump transition

In many European countries including the Netherlands, heat pumps are considered a key factor in improving the energy performance of housing, contributing to less energy use by, and more sustainable sources for, domestic heating (Kieft et al., 2021). This transition is motivated by European policy, which sets requirements for decarbonization to member states, as well as an interest in moving away from natural gas as an energy source due to ending exploitation of a gas field in the north of the country, and the reduction of natural gas import from Russia following the war in Ukraine. The Dutch demand for heat pumps increased significantly in 2022, but the market is still small (Toleikyte et al., 2023). This small market share has been explained with reference to low prices of gas, compared to electricity prices in the Netherlands (making gas-based boiler systems financially equally or more attractive) (Hyysalo, 2021, p. 144). These economic motivations are also likely the explanation behind the market increase in 2022, following rising gas prices.

Current research on supporting the Dutch heat pump transition targets households as consumers doing energy-efficient renovations and acquiring technologies such as heat pumps (Broers et al., 2019; Ebrahimigharehbaghi et al., 2019; Maghsoudi Nia et al., 2024). Proposed policy measures typically target building standards for new buildings, provision of information, or further subsidies for energy-efficient technologies or taxes on energy carriers (Boonekamp, 2007).

4.2.2. Critical use aspects of the Dutch heat pump transition

There is an increasing awareness that, beyond the initial purchase decision informed, for example, by gas prices, the use phase is a critical factor limiting uptake and satisfaction, as energy saving measures do not always have the intended result in terms of energy performance. However, post-occupancy evaluation of energy performance in buildings is still rare. In the field, such evaluations remain primarily concerned with quantifying aspects (indoor and outdoor temperatures, thermostat set points, etc.) as critically assessed by Chiu et al. (2014). These post-occupancy studies find that energy labels do not accurately reflect actual energy use in Dutch households (Majcen et al., 2013; van der Bent et al., 2022), a phenomenon also described as the performance gap. Rebound effects refer to situations where efficiency improvements from technologies like heat pumps lead to unintended increases in energy consumption, partially offsetting the intended energy savings. One Norwegian study on the rebound effect found that, compared to conventional electric heating, no energy was saved by implementing air-to-air heat pumps (Halvorsen et al., 2016). Often, this rebound effect is explained with reference to increases in comfort expectations and changes in heating practices (Brown & Cole, 2009; Gram-Hanssen et al., 2017).

This section first highlights a number of aspects that are relevant to use. Heat pumps in the Dutch context replace gas-based boiler systems. Compared to these heating systems, heat pumps present several novelties to residents. One notable change is low-temperature heating, which performs best when the thermostat is set to a stable temperature. Heat pumps operate most effectively in well-insulated buildings with larger low-temperature heat emitters, preferably under-floor heating or convector radiators, which heat indoor air slowly and evenly, rather than quickly. This means that the temperature cannot be as spontaneously adapted, and that warmth may become less noticeable to residents. Sometimes, additional fans are placed within convectors in the rooms that move hot air through the spaces more quickly, providing thermal comfort to the occupants without the need for high supply temperatures. These fans might be automated or require operation by residents. In a building with an air-tight insulated outer shell, consideration of building ventilation becomes increasingly important to ensure healthy indoor air quality (Balvers et al., 2008). The adequate performance of mechanical ventilation systems requires regular cleaning and exchange of air filters by users.

Another relevant feature of most heat pumps is their limited capacity to produce domestic hot water. Systems deal with this by heating the hot water slowly (often during the night) to 55 °C and storing it in a storage tank until needed. Typical storage tanks have a capacity of 100–200 L. A 2008 study in the UK found that the mean domestic hot water consumption per household is 122 liters a day (Measurement of Domestic Hot Water Consumption in Dwellings, 2008). This means that user behavior in terms of domestic hot water consumption (showers, hot tap water for cleaning, etc.) is relevant in terms of how often hot water is produced, and how much of it is available by the end of the day.

Several studies discuss the use phase in which residents interact with heat pumps. The studies highlight how user behavior plays a critical role. The features mentioned above, require changes to everyday practices of residents, otherwise heat pumps do not reach their predicted performance. Earlier studies have shown that during adoption and in everyday life, heat pumps require a reconfiguration of understandings (e.g., residents need to learn how these systems work), material reconfigurations (e.g., increased insulation) and reconfiguration of routines (e.g., what clothes to wear) (Hyysalo, 2021, p. 107; Judson et al., 2015; Juntunen, 2012; chapter 4 of this dissertation). These studies highlight that the heat pump transition in the Netherlands and elsewhere suffers from a lack of alignment between intended use (heat pumps swiftly taken up in daily practices) and actual use, which prompts the reconfigurations mentioned above.

These earlier studies uncovered that unexpected use practices can also have positive effects. Nyborg (2015) observed inventive uses such as Danish households' ability to modify a relay in a heat pump to shut the heat pump down completely at night. Hyysalo et al. (2013) described inventions that users made to their heat pumps and other heating technologies. The users significantly improved these technologies to match their specific situation and shared their innovations through internet forums. Similarly, a recent study found that there is innovative potential in the adaptations that users make to give heat pumps a place in everyday life (van Beek et al., 2024). This experimentation and innovation has an important potential role to play in sustainability transitions, since it could provide valuable input for the heat pump value chain (Hyysalo, 2021; Jalas et al., 2017).

Together, these studies highlight how the use situation of heat pumps is relevant to the supply side, both for realizing predicted energy savings and for potentially positive or inventive outcomes of everyday practices.

4.2.3. Some bridges connecting use to the heat pump supply side

Meanwhile, for the supply side of heat pumps, this use phase is currently mainly regarded as a challenge. In the Dutch heat pump transition, this supply side consists of heat pump manufacturers, installers, developers and implementers of monitoring and those deciding to implement heat pumps on a larger scale. For these actors it is very relevant to have correct predictions of energy consumption in the use phase as this is the informational basis on which heat pumps are sold. This information is what is used to advise installers choosing heat pump models. Such predictions determine the return on investment for their customers, but also inform decisions about which heat pump fits specific buildings and use situations. Understanding use patterns is also highly relevant to understanding how long installations will last. The use phase is also evidently relevant as the period in which complaints from end-users will appear. Such complaints might lead to extra work and failure costs, but also potentially to rejection of heat pumps by customers or a bad reputation of installations. For some actors in the supply side, the use phase is even more relevant as the current context shows the emergence of contractual binds between heat pump manufacturers, installers and end users in the form of energy performance guarantees. Breaching these can have legal and financial repercussions and might also contribute to a negative perception of heat pump technology. These factors together seem to call for developing a much better understanding of how provision (the supply side) and consumption (practices of use) interact (de Feijter et al., 2019).

However, in spite of calls for further enquiry of the supply chain of domestic retrofit (Wade & Visscher, 2021) there has been little investigation of the supply side of heat pump renovations and how it interacts with the use of heat pumps. Some studies have looked at the role of installers and other so called 'intermediaries' and found that their potential influence towards energy efficient behaviors post-installation was not realized (Owen et al., 2014; Owen & Mitchell, 2015; Wade et al., 2016). Other studies have looked at the hand-over process and its influence on user behavior (Thomsen & Hauge, 2017), or study sales and installation (de Wilde & Spaargaren, 2019; Gram-Hanssen et al., 2017) and how these practices interact with energy related everyday household practices. Another study used human-centered design to understand the service of installing heat pumps in UK social housing (Moore et al., 2015).

While installers and intermediaries are thus receiving increased interest, the role of the further supply chain has received less attention in academic research. This might be in part explained by, what is traditionally considered, a rather large gap between manufacturer and end user. An important study (again from the UK) puts this in perspective (Killip et al., 2020). The authors highlight that the operational impacts (i.e., energy consumption in the use phase) of buildings are remote from the control of manufacturers working in high-volume, mainstream markets. Manufacturers sell their product to 'merchants' (resellers), who sell to designers (or contractors and architects) who then sell to installers, who then install installations for their clients as end-users (figure 4.1.). Beyond sales, there are some links connecting the separate actors along this chain, in the form of accreditation and advice, but the length of the chain is still considerable. Manufacturers' influence on end-users is therefore generally indirect, via installers.

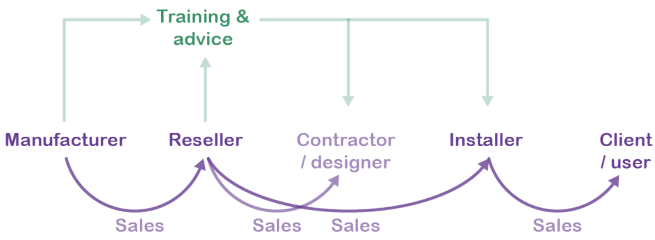


Figure 4.1. Value network relationships and activities (simplified and adapted from Killip et al. 2020)

However, Killip et al. also give several reasons for a closer connection between manufacturers and end-users. First, innovations in the sector (most notably Building Information Management or BIM, and off-site construction) alter the value network and create stronger links along the value chain. (Other studies have added performance monitoring as another innovation that creates such links (Simpson et al., 2020)). Secondly, green markets require manufacturers to stand out, and to demonstrate their expertise and experience to clients. This enables innovation, specifically beyond the project level. The authors note that *"when middle actors and end-users share a value-driven commitment to reducing building environmental impacts of all kinds, the relationships can take on the quality of friendship. However, the scale of activity among the green businesses is a long way from being sufficient to meet policy goals"* (Killip et al., 2020, p. 9). Our work responds to this call for increased activity along the chain.

4.2.4. The focus of our study

To enquire into the value to be found in the connection between the supply side and end-use of heat pumps, our study focusses on those in the heat pump value network with the capacity for innovation. This means, as also indicated by Killip et al. (2020), that we target actors working beyond single projects, who can create new links to the end user in their practices and processes. This set of innovating actors in the value network include heat pump manufacturers and resellers, but also those developing performance monitoring (Simpson et al., 2020). In addition, our earlier experiences in this field and previous work by Cauvain and Karvonen (2018) revealed that social housing providers also play an important innovating role and have a large degree of agency when it comes to installing heat pumps. They make important socio-technical decisions in retrofits (relating both to their tenants and to specific heat pump features).

4.3. Framing unintended use through a new perspective for the supply side: Improvisation in practices and professional responses

4.3.1. Perspective 1: Unintended use as risk

In section 4.2.2 we have described how heat pumps are not always used as intended by residents, and in section 4.2.3 we substantiated why this unintended use is relevant to actors in the heat pump value network. Until now, in literature, this unintended use has been primarily approached as an inadequacy of prediction. Following this view, research attempts to collect more realistic data about residents (e.g., post-occupancy evaluation) and does so to correct design assumptions (Guerra-Santin et al., 2022). On the other hand, unintended use patterns have also been regarded as an inadequacy on the side of users who do not follow the instructions given to them. Research in this line investigates how residents can be better instructed or interfaces can be designed in a more transparent way (Revell & Stanton, 2016). Such a view evaluates unintended use as a risk to energy performance. Excesses in energy consumption and further instructions are addressed as failure costs: builders and installers incur costs and engage beyond the standard activities (Love et al., 2022). Such a framing was adequately captured by the provocative title of a ESRC seminar: "How people use and 'misuse' buildings". In this seminar, practice theorist Elizabeth Shove argued for a critical unpacking of the notion of misuse (Lomas et al., 2009).

In our particular unpacking, we propose a different view of unintended use. Drawing from ideas from design research, science and technology studies and practice theory, we suggest a *performative* understanding of unintended use. We explain our perspective below.

4.3.2. Perspective 2: Unintended use as improvisation

An important goal of design research is connecting the lifeworlds of end users to the development of technologies that enter those worlds (Bayazit, 2004; Cross, 1982). These connections can take many forms (user studies, A/B testing, or participatory design). A key commitment in developing these connections is the appreciation of end users as skilled practitioners of their own lives (Gunn & Clausen, 2013). End-users are not just recipients of technologies, but have an embodied know-how of the challenges and solutions they encounter in everyday life. From such a design perspective, end-use becomes a source of innovation. The intentions of technology designers and developers are thus proposals for use, but never the only way. Modern design approaches aim to integrate technology development and end-use activities in frameworks (Giaccardi & Fischer, 2008), iterative cycles (Thoring & Müller, 2011) and feedback loops (Yilmaz & Daly, 2016). From the perspective of this stream of design research, the unintended use of heat pumps is not predominantly a risk to realizing design ambitions. Rather, the activities of end users can be seen as a way of adapting technologies to the end-use situation, and even as a form of collaboration between technology developer and end-users.

A performative understanding, inspired by practice theory (Schatzki, 2019; Shove et al., 2012) takes everyday human activity, organized in practices such as heating homes, bathing, cooking, and doing laundry, as the basic unit of analysis. People *perform* these practices in the messy and unpredictable settings of everyday life. The concept of co-performance builds on practice theory (Kuijer & Giaccardi, 2018) and argues that (next to people) technologies, such as heat pumps, are also capable of performing everyday practices; they should be considered as *co-performers*. Bringing this together, our perspective highlights the activities of residents and technologies and how they interact ('their performances'). Our performative understanding also draws on the concept of *scripts*. Scripts, in science and technology studies, are the blueprints for how humans and technologies interact (Akrich, 1992; Latour, 1992). Using this concept of scripts and looking at resident interactions with heat pumps, unintended use becomes a deviation from the blueprint for use, in other words *an improvisation on the script*.

We can further expand this framework, and propose that what happens in households (what residents and technologies do in daily life) are the constituent part of something bigger. Such a view reflects the commitment that in some respects, societal transitions are the sum aggregate of many individual changing lifestyles and daily practices (Gaziulusoy & Brezet, 2015). In performative terms than, what happens in households (interactions between residents and heat pumps) are *scenes* in the *theater play* of the energy transition. (As such this work aligns with recent developments in energy research and transition studies drawing on dramaturgical and performative approaches (Yuana et al., 2020)). The supply side of heat pumps has an orchestrating and responding role towards the scenes. Professional actors in this supply side aim to *direct* the scenes in a way that contributes to the theater play of the energy transition.

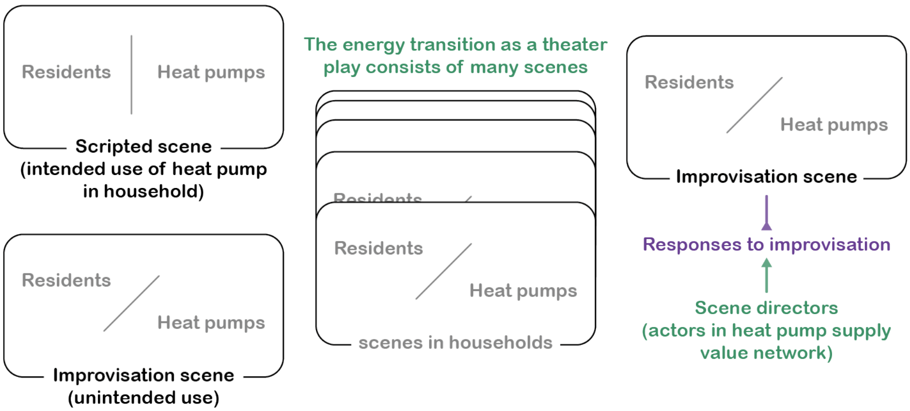


Figure 4.2. A diagram explaining our performative perspective, and the focus of this study (in red).

To synthesize our brief introduction, from the performative design research perspective (figure 4.2.) we adopt in this study, performances of residents and technologies in each household, together form a scene in the theater play of the energy transition. The word *improvisation* comes to refer to the unintended, unexpected interactions of residents with heat pumps, and other parts of an energy efficient house (e.g., the opening of windows in warm weather). We understand the activities of professionals in the supply side of heat pumps as *responses* to this improvisation. A response is something that professionals do that engages somehow with this improvisation. Responses can be something structural, built in existing workflows (e.g., a service complaint protocol), it can be a one-time intervention when improvisation is noticed (e.g., an information campaign), or it can be a change in professional practices or standards in response to improvisation (e.g., a new implementation of a service protocol).

In line with our design research attitude, some general principles can already be proposed for what might be effective responses to improvisation. First and foremost, unintended or unexpected use is not necessarily a problem, or something to be prevented. Instead, it is a form of improvisation, which might be directed, orchestrated, or regulated. To cater to this improvisation, we can propose that technologies such as heat pumps are assigned a flexible role in everyday life of residents. Such a flexible role aligns more with improvisational practices, instead of scripted use. Such technologies should be adaptable to diverse use situations ('different scenes') as no end-user situation is the same. On a higher level, we can propose that system designers and other professionals do not just carry out a project and 'leave the scene' but are involved beyond delivery, both by learning how decisions have worked out (a feedback loop) and by proposing and spreading ideas of 'good improvisations'. This involvement then requires connections to the end users by supply-side actors in the heat pump value network.

4.4. Approach and methodology[27]

Our overall approach relies on interviews for collecting data. The research methodology in this study also incorporates a design element. The video resulting from this design, functions as a stimulus in research. It serves to evoke a reaction from research participants that pertains to their real-life situation and that is relevant to the research problem being investigated. As mentioned, the goal of these interviews is to understand how participants respond to improvisation. The interview had two parts. The first part focused on participants present understanding and recollection of their practices. The second part introduced a sensitizing video as a stimulus and focused on participants responses to this video.

4.4.1. Design of the sensitizing video

As we have argued above, currently, there are few established connections between supply side and end use in the heat pump value network. We have also argued that the absence of these connections stems from particular understanding of use, which lacks a conception of improvisation, and describes deviations from intentions as misuse. This aligns with our own observations from earlier conversations with professional practitioners in the field. We have noticed that such unintended use often goes unobserved, and that there is unclarity as to how this unintended use might relate to professional practices. From earlier research, we had also learned that imagining alternative or additional professional practices responding to improvisation was difficult for these professionals.

[27] Data and materials underlying this chapter can be found on 4TU.ResearchData. https://doi.org/10.4121/1db04979-33f9-4742-b2b3-f0d6e10141ca

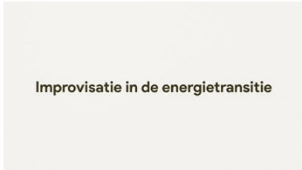
We therefore decided to prepare and include a sensitizing video in the latter half of the interviews. The purpose of this video has a function similar to a stimulus in experimental research. It is not a suggestion for future practices, but a provocation that serves to evoke a reaction from research participants that pertains to their real-life situation and that is relevant to the research problem being investigated. As such, our approach makes use of speculative design, a method common in design research, where the idea is to introduce design concepts that spark conversation and provoke debate (Dunne & Raby, 2013; A. Galloway & Caudwell, 2018; Johannessen et al., 2019). Speculative design is increasingly used as a research method as it can sensitize research subjects in relation to research questions (Alfrink et al., 2023; A. Galloway & Caudwell, 2018).

This video served the purpose of creating a baseline understanding of unintended use by the participants, to introduce them to the framing of unintended use as improvisation, and to make them aware of how their practices relate to this improvisation and how they could potentially respond to it. It does so through an explanation and illustration of the perspective introduced above. Concretely, the use context is presented as an improvisation scene. Identifying it as a scene proposes a shift from technology as the main point of attention, towards an opening idea that there are a variety of actors in the use context who dynamically interact with each other. The existence of a variety of actors, in turn, raises the question of their relationships and what emerges as they interact. Zooming out, participants viewing the video (professionals in the heat pump value chain) are positioned as directors of the improvisation scenes. Identifying them as a director proposes a shift from preventing unintended use, towards an opening idea that the director has choices on what to aim for in the interaction between the scene actors (users and technologies).

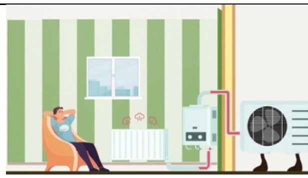
The content of the video draws from earlier ethnographic work that we did (chapters 2 and 3) and makes use of the framework as described above (section 3). Earlier ideas and drafts present in the video were presented in workshops with external experts. Based on feedback from this workshop and other stakeholders, these ideas were synthesized in a storyboard and a script for a voice-over (in Dutch) by the first author. The storyboard and script were, through several iterations, developed by an external video maker into an animated video.

The video has a duration of exactly six minutes. It consists of four parts: 1.) an introduction of the energy transition, the role of heat pumps, and the phenomenon of unintended use. 2.) an explanation of how these elements (transitions, technology and unintended use) can be understood from a performative perspective. 3.) three ethnographic vignettes from our previous research and three proposed interventions that respond to the described situation in the vignettes, 4.) a list of four principles (following from our perspective presented in section 3) which are used to come up with these responses. The video ends with a provoking question that starts the second part of the interview. Table 4.1 presents the full voice-over in translation, and several stills from the video.

We want to get rid of fossil fuels. That is why many Dutch homes need to be renovated by insulating them and removing them from gas, for example with a heat pump.
Great achievements can be made by renovating several houses at the same time and installing a heat pump. For example, in neighborhoods with social housing.
The goal is for residents to live in a well-insulated house, where it is warm, and which suits their daily needs.

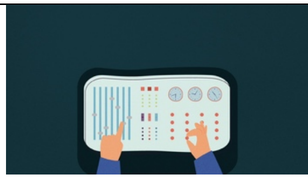


Once the renovation is completed, the installation does its work. A heat pump heats the house and the hot tap water without natural gas.
But while the installation does its work, we expect residents to do something too. But they sometimes do different things than expected and intended. We see that many residents open their windows, while they are intended to be kept closed when it is colder outside. We see that residents use more hot water than estimated. Other residents temporarily turn off the ventilation system, even though they have been told to keep it on.



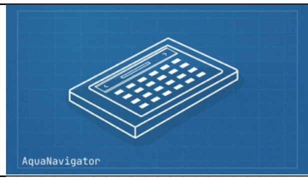
Why do residents do different things than we expect of them? And how can we respond to that?
To answer that question, it makes sense to view the household as a performance of a play. The play is the energy transition. This play consists of many scenes. Every household in the energy transition plays a scene. The scene has multiple characters. Residents and installations both have roles. The heat pump heats, but it only gets warm inside if the resident keeps the windows closed. The resident can enjoy fresh air, but only if the ventilation system plays its role and supplies fresh air.

We can partly direct this scene. We can direct the role of residents by, for example, giving them a manual. And we can shape the role of installations by setting and programming them. But people and technologies play their roles in different ways. A thermostat measures temperature, while a resident physically feels local comfort (and can therefore grab a blanket). A ventilation system works predictably based on measured values, while a resident can plan ahead based on the agenda.
In short, people (can) improvise, while installations must be predictable and cannot deviate from their script. We can respond to this. We can encourage, support or give direction to residents' improvisations by giving the right instructions from the director.
Let's look at some improvisations and how an intervention that supports that improvisation can contribute to a better scene and ultimately a better play.

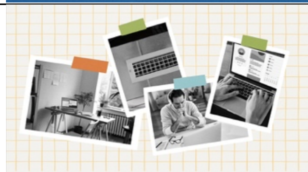


Marijn and Joost live with a family of six in an energy-neutral house. Their domestic hot water system only makes hot water once a day, and that is not enough. Their youngest son therefore sometimes has a cold shower. To avoid the cold shower, the family improvises an overview for the use of hot water every week. This allows them to determine who can shower on what day and when the dishes should be done.

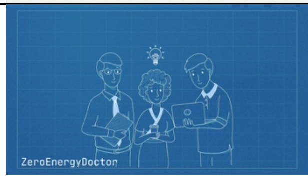
We introduce the hot water planner. This device makes it easier for residents to plan their hot water use. They can indicate when they expect to need hot water. When the hot water is running low, the device changes color to warn them. The landlord distributes this device to larger families.



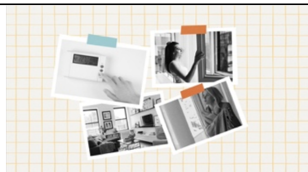
Dave turned the attic into an office. However, the ventilation system is also located in the attic and makes quite a bit of noise; too much for his concentrated work. By searching online forums for the installation guide, Dave found a way to access hidden settings that allow him to disable the system for a period of time.



We introduce the zero energy doctor. This is a volunteer energy coach. This person knows the details of installations and gathers new insights by talking to residents and monitoring online forums. This person will then explain these insights and apply them to residents in the neighborhood to help make their energy-neutral home work for them.

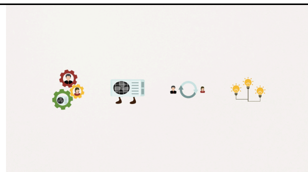


Rob and Sacha did some experimenting to get the desired internal temperature. They have discovered that it is much faster and more convenient to regulate the temperature by opening and closing the windows than with the thermostat. Now they keep the thermostat at 22 degrees and open a window if it gets too hot.



We introduce the experimenting thermostat. This thermostat is available on request for the interested resident. It does not stay at the temperature set by the end users, but experiments with them. For example, the self-learning algorithms will lower the temperature when energy consumption is high, to encourage residents to close the windows. It tries to minimize the number of times users have to intervene while reducing energy consumption.

So, how do these stage directions support the improvisation? We used these principles: Creating a dynamic division of roles between residents and installations such as heat pumps. Set up installations so that they are flexible and correctable, and thus adaptable to the situation. Creating a feedback loop from use to system designer and back. Pick up, monitor and distribute good improvisation ideas.



How can you give stage directions for improvisation? And how does that contribute to the energy transition?	

Table 4.1.Voiceover and stills from the video

4.4.2. *Interviews*

The interviews were conducted in April 2024. We used purposive sampling, targeting professionals who could provide a good overview of the process (table 4.2.). We therefore looked for larger players in the heat pump market in the Netherlands, and spoke to people in managerial, executive or representative positions. The participants were recruited through professional and research networks and trade fair contacts. Many of the participants had decades of experience in the sector and had worked in many positions, including in laborer positions like installer. We also targeted other organizations involved in this sector that contribute to innovations in the field. These included technical project leaders on heat pump projects for social housing organizations and providers of energy management systems that specifically involve heat pumps.

We were specifically interested in heat pumps, but many of these manufacturers and wholesalers are involved with other installations (such as ventilation or PVT-panels) as well. All the participants were male (reflecting the state of the industry).

	Organization	Position, current and previous
P1	Heat pump manufacturer	Project coordinator, installer
P2	Social housing organization	Head of innovation
P3	Heat pump manufacturer	Strategic advisor, director
P4 (two participants in one interview)	Heat pump (installation) wholesaler	Product owner and head of R&D
P5	Provider of monitoring and home energy management systems	Director, (co-)owner
P6	Heat pump manufacturer	Director, (co-)owner
P7	Heat pump manufacturer	Head of product management
P8	Heat pump manufacturer	COO, innovations manager

Table 4.2. Participants

Semi-structured interviews are a widely used qualitative method in energy-related research (Bavaresco et al., 2020). This approach allows for flexibility in exploring participants' experiences and attitudes while maintaining a consistent framework across interviews.

The interviews were conducted in Dutch and followed a structured guidebook to ensure consistency in the questions asked. However, the interviewer maintained flexibility, allowing for a natural flow of conversation and enabling participants to reflect on their own experiences. The primary focus was on capturing participants' attitudes and personal accounts related to the research topics.

The duration of the interviews varied between 45 to 90 minutes. While certain essential topics were consistently addressed, the interviewers loosely adhered to the guidebook for other questions. This approach ensured that the interviews remained conversational and reflective. To facilitate this, interviewers occasionally provided examples from previous ethnographic research to prompt discussion and elicit insights into participants' attitudes and practices.

In one instance, two participants from the same organization were interviewed together (both denoted by P4). Another interview was conducted in two parts, with the participant watching a video outside of the interview sessions. These adaptations were made to accommodate the participants' schedules.

The data generated from these interviews consisted of transcripts. These transcripts were produced using a combination of automatic transcription tools within MS Teams (*Microsoft Teams*, 2024) and on-device transcription using AI models, specifically MacWhisper (Bruin, 2024).

4.4.3. Data analysis

We used reflexive thematic analysis because it is a highly flexible method that readily adapts to different questions and sample sizes (Byrne, 2022; Clarke & Braun, 2017). The principal researcher took the lead in the analysis process, with the other authors contributing by reviewing the coding results. Initial findings were recorded in a new document to ensure transparency and traceability.

Our analysis was conducted with a critical orientation, meaning that we approached the data with an awareness of the broader social and contextual factors influencing the participants' responses. The analysis was predominantly deductive and theory-driven (Byrne, 2022), focusing on specific responses that aligned with our research questions and theoretical framework.

The stages of our reflexive thematic analysis were as follows. 1.) Data familiarization and generating initial codes, while correcting transcriptions for accuracy. 2.) Searching and reviewing potential themes. This initial round, based on a representative selection of the data, was reviewed collaboratively with the other authors to ensure the robustness of the identified themes. 3.) Defining and naming themes, ensuring they were distinct and accurately represented the data. The collaborative review process and critical orientation ensured that our analysis was both rigorous and reflective of the complexity of the data.

4.5. Results

4.5.1. Introduction: Responses to unintended use proposed in the sensitizing video

In this results section, we describe how professional practices of heat pump development and implementation as part of the energy transition in the Netherlands, respond to unintended use of heat pumps, or improvisation. Earlier (§4.3.), we have defined responses as *professional practices that somehow deal with unintended use, or changes to these practices when unintended use is encountered*. We have also, in the sensitizing video, proposed three responses to unintended use. Following our analysis as presented in this results section, these responses can be retrospectively classified as: 'supporting improvisation' (intervention 1), 'spreading insights (intervention 2)' and 'automated regulation' (intervention 3).

In this results section we first describe the (change to) practices brought up by professionals, clustered in seven responses (§4.5.2.). In that section we exclusively report on responses indicated by participants before being shown the sensitizing video, or without reference to the video. After that, we report on the factors that, for our participants, inform which response would be chosen (§4.5.3.), including the responses shown in the sensitizing video.

4.5.2. Responses to resident improvisation reported by participants

From our interviews we could distill seven themes that represent participating professionals' responses to improvisation. As will become clear, these responses do not exclude one another and several themes (partially) overlap.

Response 1: Investigation of anomalies

The first type of response to improvisation is to regard them as anomalies. Many of our participants mentioned that they learn about unintended use or improvisation from either energy monitoring setups (as many modern heat pumps are sold with 4G connected monitoring), or from complaints when resident heating or cooling strategies did not achieve their goals. Automated signaling often happens based on threshold levels for energy consumption or for runtime hours of heat pumps. Sometimes this is complemented with additional information from monitoring to determine if residents are home, for example. This monitoring and signaling of anomalies typically involves multiple actors. Monitoring companies (of which one participated in our interviews) or heat pump manufacturers inform building owners or managers (such as those at social housing organizations) who will then further investigate. Alternatively, residents themselves signal anomalies by filing complaints to their social housing landlords.

When no complaints are made, and no excessive heat pump figures are observed, unintended or unexpected use will likely not be noticed by our participants. Examples of such unobserved instances include ventilation practices, such as opening bathroom windows rather than ventilating with mechanical ventilation systems [P2]. Participants indicated that they were somewhat aware of such situations but also indicated that they felt insufficiently informed about unintended use.

The first thing many of our participants do when they notice deviations from expected performance (through monitoring or complaints), is investigate whether there is a technical fault. Often, in recently finished renovation projects there might be a misconnected pipe or an unopened valve. In some cases, when the issue is still not clarified, investigation continues with further diagnosis and reporting [P1] and a closer look into the performance of other households within the project [P8]. Heat pump resellers and manufacturers see this as a form of aftersales [P6].

Only when the installation does not seem to perform as expected, participants will investigate further, and discover that anomalies might originate in what residents do. Throughout this chain of signaling, unintended or unexpected use, will remain in the realm of anomalies to be solved (like technical faults) and tried to be solved case by case. However, participants also noted how the accumulation of such cases leads to learning, which we report in the next subsection. "*When the projected energy savings were not reached, it became clear that the user component has a large influence*" [P7].

Response 2: Learning and transferring learnings

All of our participants (in strategic roles, and as innovation leaders, e.g.,) see many individual renovation and heat pump implementation projects, and thereby have somewhat of an overview perspective. From this perspective, they saw patterns emerging within these projects, and were able to find similarities in multiple cases, related to unintended use. One of our participants, for example, mentioned observing that instructions in booklets about underfloor heating were not picked up by residents in a project. He then included this aspect actively in information events [P2]. Similarly, another participant had assembled learnings across projects in a video that responds to frequently asked questions at resident-oriented events, including those about simultaneous cooling and heating with heat pumps [P1]. Similar learnings also changed technical decisions about heat pump implementation. One of our participants mentioned for example how earlier assumptions about the frequency of taking a shower were wrong, and therefore adjusted the size of the domestic hot water storage in later projects [P1].

However, participants also indicated their struggles to consolidate these learning points along the whole value chain of heat pump implementation. This results in part from the distance between use and supply-side actors. Another reason is that many actors (including installers, but also renovation divisions in social housing organizations) work exclusively in projects and not in development, resulting in a lack of feedback from the use phase, resulting in unchecked assumptions [P5]. During the interviews, some ideas emerged to consolidate learning (especially beyond projects) by doing yearly evaluations together with residents [P2].

Response 3: Anticipating in technology design

All participants emphasized that what residents do is relevant, both to the sustainable performance of the complete renovation, and to the satisfaction of end users who may not (any longer) be able to, for example, obtain 24 degrees indoor temperatures in winter. *"We know that* *a high thermostat setting leads to trouble"* [P5]. Many participants [P4, P5, P7] indicate that they primarily deal with such unintended use through anticipation in the design and implementation of heat pumps. One of the reasons they anticipate unintended use is that, because compared to gas based boiler systems, heat pumps are 'not as forgiving' [P7]. They describe this as the 'boundaries of technical capabilities'. "*In case of all-electric heat pumps, what residents do is very relevant, because they run into the boundaries of technical capabilities more often [compared to conventional gas boiler systems]"* [P4].

However, participants also indicated that these technical capabilities are to a certain extent within their influence and that these 'boundaries' could be expanded to allow for some level of unintended use [P6]. For example, they indicate that if the power of the heat pump or the levels of building insulation are chosen somewhat higher than strictly necessary according to energy performance calculations and/or building regulations, this will make sure that residents do not run into issues even when they do not act as instructed or intended.

Participants expressed different positions towards such 'oversizing' of heat pumps. Some noted that unintended use is to be expected and what they considered normal, an insight they had gained from their experiences in selling and implementing heat pumps. In their view the building regulations account only for a perfect or average use situation, whereas reality shows that each situation deviates from the average (*"there are no 1,4 person households"* [P5]). As such, there should always be some space created for behaviors that were not accounted for in the building regulations or in calculated energy use. *"If installers choose to do the minimum that is going to cause problems"* [P4]. These participants therefore encourage installers (in training) to choose a heat pump with higher power than strictly required and thereby leave some room for unexpected and unintended resident activities.

On the other hand, other participants expressed the view that calculated energy consumption in principle should be achieved. From an energy performance perspective, heat pumps can heat every room in the house to, what is established in building regulations, a comfortable temperature. Oversizing the heat pumps is then considered a risk to the achieved efficiency, and residents should accept lower maximum room temperatures. In this view, it is thus not just the installations that should change in response to unintended use, but residents should change their expectations and behaviors.

Response 4: Preparing mindsets

Another response to improvisation which was mentioned by all participants was attempts to prepare the mindset and expectations of residents. In this regard, all participants, including those with technical backgrounds and orientations, had realized that renovations are not simply matters of technology rollout. Participants highlight that the transition is not just about energy, but also about knowledge [P1].

The participants were largely aware of the limitations and difficulties in preparing or changing the mindset of residents. They are aware that unintended use will happen anyway. "*We know what will happen, especially when it is existing built houses*" [P5]. All participants had realized that a straightforward instruction of use (e.g., to not touch certain buttons [P1]) is not sufficient and does not work to avoid unintended use. Many participants also indicated that explaining the technical functioning of the heat pump is unfeasible in most cases. Aspects like weather dependency and room compensation are difficult to get across [P1].

Instead, participants used a variety of tactics to varying degrees of success. The first tactic is still a form of direct advice to residents but targets one-time changes that will have a longer lasting effect. Participants for example advised residents to not put couches in front of radiators [P6], or to throw out their pajamas because these would not be necessary anymore in a house with more stable temperature levels [P2]. Participants had found that advising such one-time changes was more effective than attempting to change recurrent routines, as these one-time changes did not need to be remembered by residents. A second tactic aims to inform residents of the consequences of their use patterns. Participants tried to communicate to residents that changing heat pump settings could increase the amount of hot water available each day, but also increases energy consumption, and that long showers might lead to cold tap water at the end of the day. A third tactic targeting mindsets relies on the use of metaphors recognizable to residents, or other indirect explanations. One participant, for example, explained how older buildings can be seen as dressed in 'thin clothes' with a 'large furnace' whereas a zero-energy house should be seen as a building with a 'very thick jacket', but with a very 'small furnace' inside [P2]. Participants did also mention that with such use of indirect, non-technical explanations, there is always a risk of misunderstanding or taking the metaphor too far.

The means with which participants were familiar to carry out these mindset preparation tactics include information sheets or booklets that are delivered at installation time, events like resident information evenings or demonstration homes, and the instruction of other actors in the value chain like installers or maintenance parties to achieve a consistent communication strategy. Generally, such mindset preparation happens exclusively before, or at the moment of, delivery. The social housing organization, however, also made use of a six week 'moving in' period after which another event was organized during which further instructions could be communicated.

Response 5: Encouraging and amplifying

Several participants [P2, P3 and P6] reported being aware of, and encouraging a certain level of improvisation. They considered this necessary for residents to gain the required insight into the functioning of their home with new installations. Participants noted that such improvisation and experimentation often only happened for a short period of time. For example, even though changing thermostat settings is generally discouraged, one of our participants thought that some variation in the initial phase could be beneficial. He stated that he thought that residents might change the thermostat up and down for a little bit, and then leave it at some point [P3]. Other participants also indicated that they were not particularly concerned about unintended use. They felt that a subset of residents is always inclined to experiment *"That remains, some people like hacking systems"* [P6].

Another participant indicated that they expected improvisation to happen within a specific time period, which aligned with the information events organized when residents move in. *"We want them to play around with it for about 6 weeks in the beginning, because it gives residents insight"* [P2]. Alternatively, a full year of living with a heat pump would enable residents to experiment and experience effects throughout all seasons [P6].

This encouragement of 'unintended use' indicates a positive and accepting view towards improvisation and potential benefits. As part of this, participants also understood that making use of these benefits and amplifying them works better when residents have a certain openness to change of practices, for example when residents move houses. When residents have recently moved in, they experiment and are able to adopt new use patterns, some of which are useful or necessary for adopting heat pumps *"You throw away the old, and you're open to new rules"* [P2]. This was contrasted with renovation projects where residents stay in the home during the renovation, which they found much less likely to lead to change of use patterns. In these cases, residents continue to perform 'old practices' aligned with gas-based boiler systems, and participants found that their encouraging responses had little effect.

Response 6: Safeguarding

As there was a general awareness among interview participants that a certain improvisation would benefit the residents' learning or was going to happen anyway, participants also sought ways to make this happen in a safe way. They mentioned, for example, that they design heat pump systems in such a way that important or dangerous settings cannot be changed. Certain buttons and valves are put away in a box, intended only for maintenance professionals or installers [P4]. Next to safety, participants mention ensuring energy performance as a reason for putting in some guard rails. Participants mentioned that they *"want to exclude resident behavior"* [P4], as they consider certain behaviors too detrimental to the energy performance of the heat pump. Part of this safeguarding strategy is the limiting of energy consumption. Participants reported that they limited the total flow of hot water out of the domestic hot water storage. This prevents excessive hot water use from extreme use cases. [P8]. On the other hand, participants also used building automation to make sure that even when unintended use happens, resident health will be protected. *"You'll be fine if you [the system] just ventilate based on CO2 levels"* [P4].

Response 7: Directing, accommodating and incorporating

Some participants had developed experience in being responsive to improvisation in a more integrative and accommodating way. These participants do not just safeguard, but also provide subtle cues and guidance to residents that would shape how they interact with heat pumps. One participant [P2] explained how a particular household had felt cold in certain places in the living room. Even though the general advice would have been to move the couch to a different place, in this case, the involved technician simply slightly changed the direction of outlet vents from the ventilation system. Similarly, installers and heat pump manufacturers will often remotely change a setting to accommodate and optimize for a particular use case (e.g., turning off an eco-setting which makes the heat pump produce more domestic hot water for households with higher consumption [P8]). The position of the social housing organization allows for even closer involvement. One of the participants [P2] recalled how a resident had to use the bathroom repeatedly at night due to an illness and was annoyed by the noise. Such frequent use of the bathroom was unpredicted and could be considered unintended use. However, our interview participant decided to temporarily turn off the ventilation in the bathroom, just to provide some more comfort.

In another case, a participant mentioned how residents played around with and changed the settings (the heating curve) of their heat pump. This was reported on an online forum. The heat pump manufacturer noticed this and responded positively. This participant then also went to this residents' home and tested out which settings worked best in that specific case [P8]. In a more extreme example, this heat pump manufacturer incorporated a resident's technical skills in living with their systems within the manufacturers organization. When a resident complained about heat pump interfaces, the heat pump manufacturer offered this person a job, which he took /P8].

These deeply involved, directing and accommodating responses to improvisation tend to be small scale, local and labor intensive at present. Yet the examples show that they brought important benefits for residents: wellbeing, comfort, ownership over and insight into energy use. They also brought important benefits to participating professionals: insight for system optimization and communication with residents, and in an extreme case, acquiring a skill set for their organization.

These directing and accommodating responses also redefine the notion of unintended use, and appreciate it as a form of improvisation. As professional practitioners become more closely involved with improvisation by residents, they work together and propose experiments and different use patterns. Such experiments can also be part of the diagnosis of unexpected issues. Professional practitioners can suggest to try something and see if it works [P8]. This can ultimately lead to optimization or potential redesign of the technology itself.

4.5.3. Factors for evaluating proposed and new responses

In this section we identify the factors that, according to our participants, shaped which response to improvisation they would choose. This approach will enable us to identify effective best practices (from the listed responses) and investigate what enables or hinders the integration of these responses into professional routines. Determining these factors also is a starting point for understanding which of these barriers can be taken away. In addition to the responses brought up by participants themselves, identified in seven clusters in section 5.2., participants also benefitted from having watched the video. In the video, as described earlier, participants were sensitized to a particular framing of unintended use, and were introduced to three particular responses (supporting improvisation, spreading insights, and automated regulation).

Observability

While monitoring setups and resident complaints enable professional actors to observe some aspects (e.g., out of the ordinary energy consumption), many aspects of use remain hidden. *"We know about thermostat settings, but not about door openings"* [P2]. Participants highlighted that, even though they found unintended use very relevant, they were limited in the extent to which they could observe it and thereby respond to it. Use related factors often come to the foreground only during investigations or further reports in case of some incident (c.f. 5.2.1.). Observability is thus a factor that hinders choosing more extensive responses.

Positions and responsibility in value chain and network

The value chain of heat pumps has many actors with different responsibilities. As such, manufacturers have previously directed some responsibility to other actors (most notably to installers and maintenance parties) in responding to improvisation [P4]. Meanwhile, they also recognize that installers are seldomly involved beyond the delivery of a project, unless there is a major problem.

Installation wholesalers, from their position in the value network, regard themselves as responsible for delivering installations and their technical performance [P6]. These parties see themselves as limited in further engagement beyond the installations themselves, and do not primarily interact with residents.

On a smaller scale, social housing organizations have some internal distance between those making technical choices and those responsible for end-user. Upon delivery of a project, the responsibility for the buildings in operation transfers from a department responsible for renovations, to a regular 'customer care' department. The responsibility of the former is concerned with energy consumption and household behaviors but only in planning and prediction, while the latter primarily responds to complaints [P2] and is thus more closely involved in the use phase.

Meanwhile, as shown above, these positions in the value chain are changing, enabled by connectivity (4G monitoring) and further spurred on by financial structures such as 'performance guarantees' where building owners are sold heat rather than an installation [P6]. These innovations enable (and require) for new actors to be involved beyond delivery and into the use phase.

Legislation and contracts

Participants reported that legislation and legal frameworks, such as GDPR, restricted them from responding to improvisation. For example, the monitoring company, while able to observe collected data and draw conclusions about unintended use, is, as an external party, not allowed to respond or further investigate [P5]. Although social housing organizations have more possibilities in this respect, they as well are bound by regulations and contracts to not intervene in residents' households. For illustration, they cannot directly correct residents when they observe that windows are opened [P2].

Participants also reported that emerging legislation in the Netherlands might require installers to guarantee the performance of heat pumps and resulting energy savings. Although there is currently unclarity about the development of these regulations, participants reported that such regulations could potentially require installation parties to become more pro-active in the use phase in order to guarantee energy savings even when residents do not use heat pumps as intended [P7].

Perceived capabilities of residents

While interventions such as additional advice or household facing monitoring apps are seen to potentially contribute to directing improvisation and use patterns, it is also important that residents understand the information presented to them, and have the capabilities to interpret them [P1, P8, and 5]. Participants noted that they actively struggled with this understandability as heat pumps, and low temperature heating, are new and complicated to communicate to some residents [P7]. The perceived capabilities of residents are thus a factor that determines the responses by professional practitioners in the supply chain.

Technical possibilities

Participants expressed an interest in further home automation, monitoring and automated signaling of deviations to residents. Such a smart system would provide guidance and solve complicated situations in the most optimal way for the residents. *"Ideally, we would have some sort of digital butler"* [P5]. However, participants also felt restricted by technological possibilities. They mentioned that often an ideal response would be an on demand or ad hoc replacement of the installation in case of a change of situation. For example, a larger family moving in needs a larger hot water storage, but a quick replacement is costly and technically difficult. Technical possibilities thus also determine the choice of response.

Perceived norms

Participants expressed that there are written and unwritten norms regarding what is considered 'normal' and strange use. Buildings (and building regulations) are designed for averages. One participant for example mentioned: *"the system is designed for, what is it, 1,4 people? I have never seen a 0,4 person"* [P5]. One could argue that any deviation from what a system is designed for can be considered unintended use, but participants highlighted that they used a situated and nuanced norm, for example for the size of households. They would only respond to excessive deviations from this norm, and be less interventionist when they observe more moderate anomalies.

Such a norm was also more implicitly present in the limitation of domestic hot water flow described above (§4.2.6). The participant mentioned that such a limitation would not be an issue for most showerheads, while some 'tropical rain shower heads' would not receive enough water. These kinds of showerheads were thereby considered out of the norm [P8].

Organizational capacity

Participants mentioned that they had only limited time and resources available to respond to unintended use. Some mentioned they don't have the capacity to monitor everything [P8] while others reported being too busy to respond and had to *'just wait till it breaks'* [P5]. This pressure is further exacerbated by staff shortage in the installation sector and the current pressure for a fast energy transition [P7].

In a similar vein, participants highlighted that the capacity for innovation and learning beyond single projects is difficult in the complete value chain, as many installers are small and do not have the extra time available. However, currently, the Dutch installation sector is undergoing a consolidation, where larger firms incorporate smaller ones. This consolidation creates the organizational capacity for innovation and new responses [P7].

Resident autonomy and responsibilities

Participants found it important to respect resident autonomy when it comes to energy use, and thereby refrained from responding too early. *"We're not here to force a low energy bill"* [P5]. Multiple participants expressed a negative view towards what they considered 'patronizing' responses [P1, P2]. Social housing organizations were also aware that too much intervention 'behind the front door' can cause internal household conflicts, in which they did not want to meddle [P2]. Instead, many emphasized the need for voluntary participation by residents in initiatives that guided their use patterns.

Similarly, some participants expressed that they regarded it as their responsibility to advise residents on choosing the right heat pump that would *"make them happy"* [P4], while how they operate it, is ultimately the residents' responsibility.

Household diversity and scalability

Participants emphasized that they aim to tailor their responses, when possible, to specific households. There is a general awareness that residents are diverse, and thereby benefit from different responses. In eco-neighborhoods, for example, there is a high interest to experiment not only with technology, but also with use patterns [P8] (i.e. to improvise), something that participants did not expect from other neighborhoods. Responses that are appropriate to these more experimental settings might not be scalable. In this regard, participants also accept that a certain level of *"hacking is always going to happen"* [P6], but would intervene if this happened on a larger scale.

The education of installers is seen as a way of scaling and repeating the impact of responses. While heat pump wholesalers find it difficult to respond to resident diversity and individual use patterns because of the large numbers of heat pumps they sell, their educational programs can encourage installers to customize their responses [P1 and P7].

4.6. Discussion

This research highlights the crucial and overlooked role of improvisation in resident practices and the responses of professional actors on the supply side of heat pumps. We have argued that the field has largely been unable to address improvisation because it has lacked a perspective through which to study it. This research has introduced such a perspective and then showed how using it reveals existing responses as well as the potential for the development of new practices. This study is, to the extent of our knowledge, the first to study in depth the responses of professional actors in the heat pump value network to improvisation in households. Compared with earlier work on the relevance of the use phase to the supply side, our results describe in more detail the practices and actions by which heat pump manufacturers, resellers and other relevant actors engage with unintended use. Our results have confirmed that household improvisations we found, turned out to be of critical influence on the goals of the supply side (sustaining business models, accomplishing predicted energy savings locally, and realizing the energy transition at large). These responses emerge from dominant perspectives on value chain configurations, in which end-users and heat pump manufacturers are separated by a chain of resellers and installers.

4.6.1. Reflection on the results

This research showed that when interviewed from a perspective that foregrounds improvisation, professionals in their practice respond in a variety of ways to improvisation (unintended use of heat pumps). The seven responses discussed in the result section expand on our original three responses presented in the video (supporting improvisation, spreading insights, and automated regulation). This brings the total number of responses identified in this study to ten. This research has also identified which factors are relevant to the participating professionals in evaluating and deciding which response to choose. We have identified nine factors. Together, these are shown in figure 3. In the text below, the responses are indicated with R1-R10, and the factors with F1-F9.

The seven responses that emerge from the interviews are (although not described in these terms) also present in existing literature to various degrees. The investigation of anomalies (R1), reviewing first the technical performance, followed up by analysis of what users do, is a well-known emerging approach, but until now mostly applied to public buildings and not to homes (Wang et al., 2021). Although learning between different actors in the supply chain is seen as an urgent topic for contributing to energy transitions (e.g., Soleymani et al., 2023), learning from end-users (R2) is currently rarely discussed in literature. Instead, the focus in the use phase is almost exclusively on technical energy performance. There are however some energy related studies that assign the user a clear role in identifying and solving technical problems (Weigert, 2022). Weigert's study aligns with response R2, but also incorporates elements of R7, as, in his proposal, heat pump users receive simple instructions and guidance for solving technical issues in an experimental way.

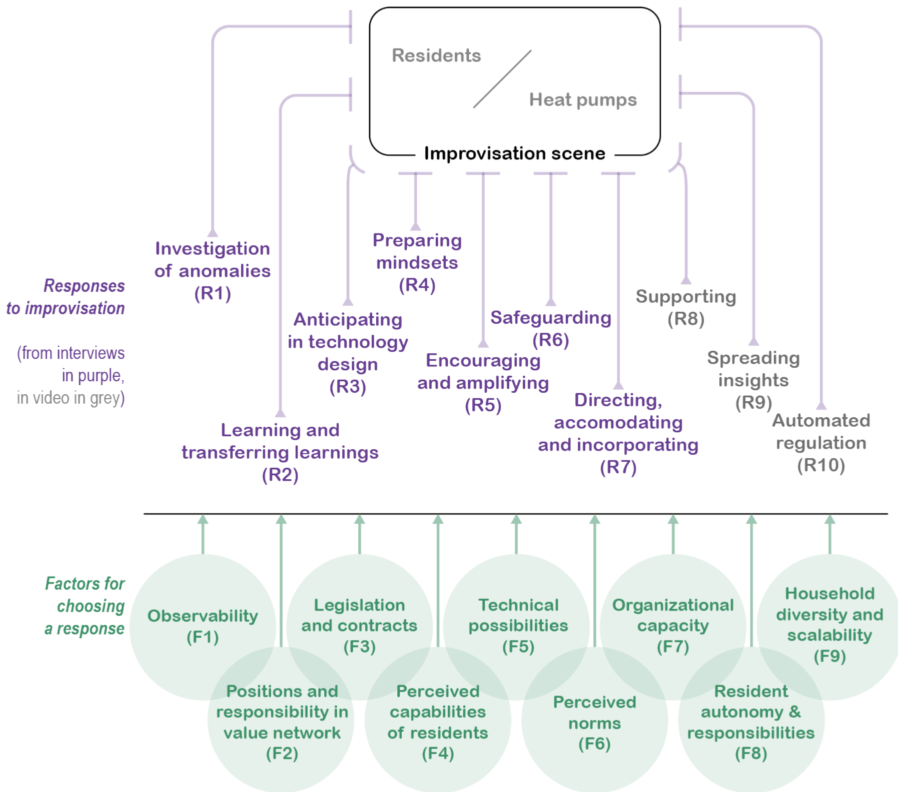


Figure 4.3. Results of our study: responses to improvisation (numbered R1 to R10) and factors for determining a response (F1 to F9)

Meanwhile, literature in energy performance research increasingly suggests approaches for connecting heat pump supply-side actors and users that integrate some of the responses also mentioned by our interviews. Wade and Visscher (2021), for example, mention service-related pricing (heat-as-a-service) and performance guarantees as ways in which occupants become engaged in the supply chain. Such new (financial) structures where a single organization oversees the entire retrofitting project, require at least some of the responses to improvisation (e.g., R4: anticipation of improvisation and R6: safeguarding). Similarly, de Wilde and Spaargaren's (2019) proposal to consider not only the renovation process, but also the use phase as a complete 'customer journey' suggests a closer connection between supply chain and use. However, this study is not very explicit on what these connections could look like beyond written public customer reviews of supply-side actors. The role of the supply chain interacting with users post-installation is also confirmed by Owen and Mitchell (2015). They highlight that these interactions (primarily in the form of instructions) should respond to users interests and have the potential of guiding energy use. This closely aligns with a directing response to improvisation (R7).

However, the literature details very little of what these new relations between user and supply chain could mean for improvisation or unintended use. This was confirmed by our participants who uncovered the tensions and opportunities that emerge from these business models 'on the go'.

However, there is existing literature on this. Moore et al. (2015) mapped different service touch points in the user centered design approach of renovations. This study, firstly, emphasizes the necessity for understanding the system in use. It highlights contact points such as home visits and telephone lines to the landlord or contractors are ways in which the expectations of users can be managed (R4). This study again highlights the importance of connecting to users 'post-installation'. Importantly, this study also finds a significant role for neighbors in influencing heat pump use. This aligns closely with our own proposed response of spreading insights (R9). Moore et al. also discuss the adjustment of settings in collaboration with and according to the preferences of residents. This aligns with the regulation (R10) and accommodation (R7) discussed in our study. The authors (Moore et al., 2015) also mention that this is an area that requires significant research as it will be difficult to ensure adjusted settings are energy efficient. These factors were also discussed by our participants (F5 and F9).

Another high-level approach that includes several collected responses is proposed in literature on households' role in transitions. Here, the emphasis is on everyday life as a source of expertise, and of user innovations (Jalas et al., 2017). This work also confirms the role of online forums as a way of collecting and spreading insights (R7 and R9). While this work on transitions primarily targets governments, the approach could be integrated with supply-side activity as suggested in our study, in particular responses that create a direct and more immediate feedback relationship between use and development (R5, R7, and R9).

The ten responses do not exclude one another, and in an important sense also rely on each other (e.g., one has to notice an anomaly first, before it can be further directed). The different responses require different capacities and labor from actors in the supply chain. For example, while an investigation of anomalies (R1) is (initially) relatively straightforward, the 'preparation of mindsets' (R4) requires a lot more effort. It also requires roles and expertise that heat pump manufacturers, as companies with a primarily technical expertise are less familiar with. The various responses require time and effort from actors in different stages of the process. Anticipation (R3) and preparation (R4) happen primarily in the earlier stages of a renovation project. Meanwhile, it should be emphasized that, according to our participants, these responses are also part of a feedback loop, and inform further actions in the same and other projects.

The interviewees displayed a strong interest in the role of the user side. However, they also showed some hesitance towards intervening too strongly. This might be partly due to their historically distant position in the supply chain from end-users (F2). But they also frequently mentioned the autonomy of residents (F8). This factor was specifically mentioned in relation to responses that more noticeably intervene what residents do (R7, R10). Interviewees expressed that they did not want to be too directive, or too interventionist, but rather stayed in the background with responses that are less identifiable as their actions.

A final observation is that participants were reluctant to discuss societal norms (F6) as relevant in informing their responses. Words like 'normal' were often used in reference to energy use, thermostat set temperatures or shower durations, but without a clear reference for what informs these norms, and how they (could) change.

4.6.2. A new perspective for the supply side of heat pumps

One of the objectives of this research was to investigate how a new perspective that connects the heat pump supply side to use patterns in households highlights areas for new relations between them. Our study opened a perspective towards closer relationships between end users and the heat pump supply chain. From our performative perspective informed by design research, unintended use is not a set of failures that are to be eliminated but a set of positive approaches that can be integrated and built upon and that potentially adds value to the value chain. This perspective gives more texture to what Killip et al. (2020) describe as the potential for a 'value-driven commitment to reducing building environmental impacts' shared between the heat pump supply side and end-users. Realizing this potential requires closer relationships involving communication, education and feedback loops with the 'quality of friendship' (Killip et al., 2020, p. 9) and a large role for various forms of trust between all actors (de Wilde, 2019). This potential is enabled by innovations such as performance monitoring, post-occupancy evaluation informing the design decisions, renovation as a product (Konstantinou & Heesbeen, 2022) and experimental approaches to energy transitions such as living labs. This new perspective is aimed at integration, feedback loops and with an appreciation of households as actors and co-innovators in energy transitions (figure 4.4.). Such a view recognizes that in the current context, no longer is the design process something that happens before production; rather, we see an intertwining of development and deployment. In this sense, design becomes more about the dynamics of relations between end-users, technologies and actors in the supply chain ('co-performance'), instead of designing precisely the intended use of a technology (Giaccardi & Redström, 2020).

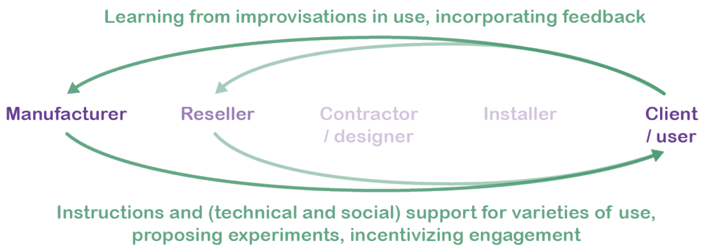


Figure 4.4. New relationships in the heat pump value network

Both perspectives (the dominant view linked to current configurations where unintended use is seen as risk (§4.3.1.), and the emerging view towards new network relationships where unintended use is seen as improvisation (§4.3.2.)) are present in our results. In the table (table 4.3.) we further distinguish them. As the three responses we propose in the video were specifically informed by the new perspective, and not by the current value chain configuration, the second column is empty in these three rows.

The emerging perspective towards new relationship was (at least in part) suggested by the video we used as a (provocative) stimulus to generate knowledge. This video was developed as part of this study. It was based on a much longer engagement with the field, and developed in a design cycle that included reflection on earlier ideas with potential participants in a workshop. While it was successful in eliciting responses in the interview that incorporated this perspective, the video itself was also a prototype tested for its functionality in reframing unintended use from an old to a new perspective in this particular audience. Upon watching the video, many of our participants commented on how it closely connected to our earlier discussions about their activities and views on unintended use, which we had discussed in the first part of the interview. Participants were also successfully able to distinguish the presented perspective as notably different from the dominant view in the field. Several participants were able to quickly point to or come up with innovations or structures that align with the newly introduced perspective (column 3 and 4 in table 4.3.). They were also quick to identify where concrete proposals, such as the interventions presented in the video, were not the most feasible or desirable responses and challenged by many existing structures in the field (such as legal frameworks and other factors F1-F9). Some, but not all, participants quickly adopted the vocabulary presented in the video (referring, e.g., to residents as actors in a scene). However, the question remains if the (temporary) change of perspective adopted when watching the video had any lasting effect in the future professional activity of interview participants. Participants need to get used to new ideas and perspective and paradigm changes. Realizing this change in practices requires a much deeper and longer embedding of these thinking probes (or stimulus) in organizations and practices (Wenger, 2000).

Response of supply chain actors	**How the responses relate to current perspectives on the value network**	**How the responses could relate to a proposed new perspective of relationship building in value networks**	**Implications: Socio-technical innovations with potential for amplification of new relationships**
Investigation of anomalies	Aimed at optimizing performance and preventing or repairing technology or user faults.	An integrated part of a feedback loop, where anomalies form part of a learning cycle that is of interest to technology development	Monitoring setups and feedback mechanisms (similar to complaint lines) that can observe relevant aspects of use (and not just faults).
Learning and transferring learnings	Learning within projects, where lessons remain tied to specific use cases.	Learning over the course of different projects, where lessons are integrated into technology development and future project structures.	New organizational structures (e.g., innovation divisions) and setting up closer connections between different actors in the supply chain. Making time for innovation and improvements over the long term.
Anticipating in technology design	Avoiding 'problems' for residents.	Deliberate anticipation of, and a flexibility for buildings to be adapted to diverse use patterns.	Developing heat pump and installation designs that are flexible to diverse situations (by e.g., being modular).
Preparing mindsets	Preventing misuse and setting correct expectations for end-users.	Preparing end-users for continued learning.	Providing learning materials on the use of heat pumps, which are dynamically updated based on resident feedback.
Encouraging and amplifying	Allow some improvisation, as it	Encouragement of improvisation as a driver of learning for	Creating platforms for sharing user experiences and innovative uses,

	cannot be prevented entirely.	both end-users and supply chain actors.	incentivizing user (and community) engagement.
Safeguarding	Prevent residents from acting in ways that might harm energy performance.	An integrated approach which allows for diverse use patterns without compromising safety or energy performance.	Developing guidelines and smart systems that can automatically adjust settings to maintain closer to optimal performance and safety.
Directing, accommodating and incorporating	Removing (potential) causes of discomfort for residents.	Building long-term relationships between residents and the supply chain.	Paying close attention to existing places of resident feedback (e.g., online forums) and establishing new channels for continuous communication and feedback, incorporating resident suggestions into ongoing product and service improvement. Proposing experiments to end-users.
Supporting improvisation	[n/a]	Support for improvisation by end-users as technology developers can learn from this.	Creating adaptive interfaces, automations (e.g., smart thermostats) and household tools that can accommodate and potentially encourage resident improvisations.
Spreading insights	[n/a]	Discovering and finding where improvisation resulted in valuable insights for improving energy performance, and spreading these insights among other households.	Developing platforms and networks for knowledge sharing, possibly facilitated by digital tools and social media.
Automated regulation	[n/a]	Enabling both foreground and background roles for heat pumps which facilitates many	Implementing systems that, automatically and/or with intervention from supply-side actors (e.g.,

		different use patterns, rather than just the intended use.	remote change of settings) can adapt to user behavior and environmental conditions.

Table 4.3. Summary of our discussion: Responses from different perspective, and potential for amplifying these responses through socio-technical innovations.

4.6.3. *Towards socio-technical innovations*

In general, one of the objectives of this research was to establish a perspective that connects the heat pump supply side to the diverse, unintended, dynamic, and potentially innovative, use patterns in households. Based on the evaluations of the different responses (§5.3), we also propose ways in which the forming of these new relationships can be amplified through socio-technical innovations. These can be found in the last column of table 4.3. These can be found in the last column of table 3. They are not all entirely novel. However, their contribution lies in their alignment with a proposed perspective of openness to improvisation. With this perspective, we offer a way for value network actors to move beyond an underdetermined 'normal' response and instead embrace a path towards an exploration of use. Potentially many more could be identified.

How do these socio-technical innovations produce effects in line with the new perspective? These proposals are socio-technical innovations, innovations that integrate social and technical perspectives and interact with both social and technical phenomena (Lowe et al., 2008). This means that they go beyond a narrow focus on technical improvements, but they also go beyond a narrow focus on social improvements. Socio-technical innovations do not (directly) address technological optimization of heat pumps, but do integrate technologies when they benefit the goal of these innovations: to form new relationships between heat pump use and supply side. What these proposals have in common is an acceptance that improvisation with heat pumps will happen, while also recognizing that this improvisation can be guided, directed, and even incorporated in the heat pump supply-side activities. These proposed innovations also propose an explicit space and time for improvisation. It might, e.g., be most beneficial to encourage improvisation when residents have newly moved in. Similarly, it might not be necessary (or feasible) to involve all end-users of heat pumps in a feedback loop. Instead, more attention can be paid to willing, enthusiastic or influential residents in specific neighborhoods or other environments (such as online forums). Ultimately, these socio-technical innovations should benefit both heat pump design choices, and their performance (in terms of efficiency and delivery of comfort), but this research has highlighted that the journey towards these optimizations requires improvisation and response.

Another key aspect to highlight about these proposed innovations is that they rely on feedback loops. These feedback loops are both short (e.g., changing certain aspects of a heat pump or its programming in a project when it is in use) and long (e.g., learning about end-users from executed projects through e.g., post-occupancy evaluation and incorporating lessons in future projects). The proposed innovations rely on (early) participation of residents. This engagement goes further than passive sharing of information or quantitative monitoring. We acknowledge that this requires time, effort and (interpersonal) work. It is possible that the technical actors on the heat pump supply side have less familiarity and explicit skills in the interpersonal domain. The heat pump value network encompasses various potentially conflicting values among actors, with business models, innovation, and energy performance goals not always aligning seamlessly. Potentially new roles should emerge, or roles should shift to bridge the technical and social domains. While our focus lies on business actors, assigning responsibility to the heat pump supply side for reducing energy consumption in everyday use might also benefit from new policies from governments (subsidies, regulations, etc.) (de Feijter et al., 2019).

Our study made use of and proposed a particular perspective, one informed by design research. This perspective has enriched our view of the relationship between the supply side of heat pumps and use. Such a perspective is not the only one, and arguably many different perspectives are necessary for succeeding in increasing the rate, depth and success of heat pump renovations in the energy transition. We hope we have contributed a part in creating room for socio-technical interventions.

Future work should develop the illustrative socio-technical innovations into more concrete and realistic interventions that work in practice. Our research has revealed the factors of importance to value network actors that should be considered in this development. In parallel with such an action-oriented approach (required to increase the rate, depth and success of heat pump renovations), there is also a need to reflect on and further develop our understanding and sensitivity to the role of heat pump end users. Currently, there is a lack of knowledge of situated action in household and the factors that determine and disturb everyday practices (such as the introduction of new technologies). A design research approach is valuable for developing both knowledge and interventions in a continuous and co-creative feedback loop. Given the high level of uncertainty and complexity in this field, initial attempts at socio-technical innovations may not be successful, underscoring the need for experimental approaches and spaces and feedback loops to foster innovation in protected niches.

The qualitative nature of our study presents several limitations. The results are illustrative and insightful but might not be generalizable to the whole heat pump supply network or beyond, due to the limited number of participants. While we aimed to provide an overview of the Dutch heat pump sector, our analysis was based on reported practices (responses) rather than direct observation. Additionally, many practices we encountered were not evaluated in detail and were sometimes mentioned only as ideas or one-time occurrences rather than consistent, structural practices. Consequently, the applicability of these responses remains uncertain, and we did not rank or evaluate them comprehensively. Our study also excluded numerous factors, such as early phases of product development, the moment of installing heat pumps and the construction period.

4.7. Conclusions

The objective of this research was to innovate in the relationship between sustainable technology suppliers and users, using the example of heat pumps. We have done so by uncovering existing and new connections between the heat pump supply side and the diverse, unintended, dynamic, and potentially innovative, use patterns in households. We have established a design research perspective that appreciates practices of use as improvisation, and the activities of the supply side as responses to this improvisation. Through a video, we have shared this perspective with actors in the heat pump supply side. We have collected their responses to improvisation, both suggested in the video and in their professional experiences. We have proposed ways in which these responses, from our perspective, could be amplified in socio-technical innovations that connect heat pump value chain and improvisation in use. We have argued how such socio-technical innovations are estimated to contribute to energy efficiency and better relationships between households and heat pumps.

5 REPRESENTATION 1: THE SCREENPLAY[28]

Over the course of this dissertation, we developed a conceptualization of everyday practices with technologies in transitions. This chapter picks up the argument introduced in chapter 2, that those practices, performed by humans and technologies together, enact interfaces: new connections between performers through which they become aligned. In this chapter, we will argue that current methods in design research for analyzing interactions between humans and technologies are insufficient in representing and understanding important features of everyday practices. There is a need for new instruments that can represent the *temporal dimension* of human and technological performances, while also appreciating the notion that every technological performance is based on, or contains, an *idea of appropriate practice*.

In this pictorial chapter, targeted at design research, we introduce a design methodological proposal that highlights these relevant dimensions of everyday practices with technologies in transitions. Using the visual vocabulary of the *screenplay* or movie script, we represent and annotate scenes from the ethnographic data presented in chapters 2 and 3. This vocabulary and its associated dramaturgical approach offers a range of sensitizing concepts (such as characters, props, and time) which might be helpful to design research in analyzing and anticipating everyday practices with technologies in transitions. Operationalizing these concepts as relevant dimensions of everyday practices in a visual vocabulary addresses research question 3 of this dissertation.

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[28] This chapter has been published as a pictorial at the 2023 IASDR conference. Van Beek, E., Giaccardi, E., Boess, S., & Bozzon, A. (2023). Making a scene: Representing and annotating enacted interfaces in co-performances using the screenplay. *IASDR Conference Series*. IASDR 2023: Life-Changing Design. https://doi.org/10.21606/iasdr.2023.788
The pictorial has been slightly edited to fit the layout of this dissertation, to avoid repetition in reporting ethnographic data, and to make it consistent with references to previous chapters.

5.1. Introduction

Automated and connected technologies are increasingly present in everyday life. In smart buildings, for example, residents and homeowners implement motion-controlled lights, smart thermostats, and connected door locks. These technologies carry out tasks and judgements ('when to heat a room') alongside humans.

This situation presents design researchers and practitioners with a challenge: How do we understand 'the matching of people with things' (Pickering, 2000) when both humans and technologies perform tasks and judgements? And what is an appropriate vocabulary to describe and envision these dynamic roles and relations, and situated interactions?

In this chapter we adopt the notion of co-performance, as a perspective on the role of artificial agency in everyday life (Kuijer & Giaccardi, 2018). Based in theories of practice, co-performance considers computational artefacts capable of performing practices (everyday activities, tasks and judgements) alongside people.

Although the notion of co-performance is increasingly adopted to study and design roles for automated and connected technologies (e.g., learning systems (Viaene et al., 2021) and intelligent agents (Kim & Lim, 2019)), until now, there is no specific vocabulary to describe and envision these co-performances.

In this pictorial chapter, we 1) propose a novel visual vocabulary for representing and studying situated co-performances based on the screenplay, and 2) present insights regarding situated co-performances in smart buildings and how they can be understood as enacted interfaces.

5.2. The lens of co-performance

5.2.1. Human and non-human performers of everyday practices

Co-performance recognizes the doings (or performances) of technologies as relevant to understanding the relation between people and technologies in everyday life (Kuijer & Giaccardi, 2018). Technologies, when acting alongside and without the direct involvement of humans, are part of the unfolding of everyday life, as much as humans. Both humans and artificial performers learn in everyday practice (by being repurposed in new roles and through new product generations).

5.2.2. Judgements, know-how and ideas of appropriateness

In co-performance, everyday practices involve know-how (an idea of appropriate forms of action (Reckwitz, 2002)). Human performers performing practices (e.g., laundry) integrate a know-how of what is appropriate practice ('what is clean laundry?'). For artificial co-performers this know-how exists in their specific embodiments and automations (for example 'washing machine programs') (Kuijer, 2019). This technological know-how is based on an underlying reasoning about what is appropriate practice, applied by designers in the design process.

5.2.3. *Crises, conflicts and response*

Ideas of appropriate action can be different between human and technological performers (judging 'how much detergent to add to laundry'). When these conflicting judgements manifest in everyday life, this can lead to 'everyday crises of routines' where there is no tested, routinized way of continuing the routine (Reckwitz, 2002)). From a human perspective, this means that a technology messes up its judgement of appropriate practice ('the washing machine is wasteful, and adds too much detergent'). Humans might, however, be able to respond to these misjudgments, and repair or correct technological performances. In this way, a new and improved match between human and system performances might be realized (limiting detergent supply in the washing machine), to which technologies again respond (by signaling a detergent supply error).

5.2.4. *Interfaces in co-performance*

The word 'interface' brings to mind a graphical user interface (GUI): a display, a graphical space, aligned with interactive elements such as physical or virtual buttons. Humans interact with information or machines through this device. This makes sense in the familiar paradigm of user centered design, where researchers and designers are primarily concerned with user experience, control, usability, and information (Bødker, 2006). In sustainability, this often entails eco-feedback (Hargreaves et al., 2018).

However, as discussed in chapter 2, what has come to be indicated as 'interface' is just one 'solution to the problem of matching people to things' (Pickering, 2000). Through the lens of co-performance, the matching of people to things does not happen (exclusively) through a GUI. Instead, we suggest that interfaces can be understood as enacted in practice, through human and non-human performances. Specifically, where know-how or ideas of appropriateness conflict, everyday crises of routines occur. Through the resolution of these crises, human and technological performances match. This new matching (or entanglement (Frauenberger, 2019)) of residents and buildings is then a new interface, not designed a priori, but enacted in everyday practice.

5.3. A visual vocabulary for co-performances

5.3.1. *Representations of co-performance*

Co-performances have been analyzed, represented and envisioned in multiple ways. The work that introduced the concept (Kuijer, 2019), for example, draws primarily on thought experiments on laundry and textual historic analysis of domestic heating (Kuijer & Giaccardi, 2018), tracing the changing roles of humans and technologies through time. These analyses are further detailed by listing the work carried out by technologies, and the work done by human performers, and how this has changed over the past century. In contrast, Viaene et al. (2021) envision and analyze possible future scenarios by bringing together a short fictional text from the perspective of a human and a list of the sequential actions carried out by technologies. Kim and Lim (2019) give form to their 'co-performing agent' by devising a script of text-based conversations on a mobile phone screen. This earlier work reveals that arrangements such as sequences of action, roles, contrasting lists, and the highlighting of different perspectives can be useful ways to represent co-performances.

5.3.2. *What a performing arts vocabulary promises for representing co-performances*

Interaction design has a long history of engaging with the performing arts; arguably all the way from Grey Walter's cybernetic tortoise (Pickering, 2010), through Laurels 'Computers as Theatre' (1993), to Bleeker and Rozendaal's dramaturgy for devices (2021) and the use of film as design experiment by Lindley et al. (2020). Often, this entails the integration of performative activities (scenarios (Iacucci et al., 2002), roleplay (Boess, 2006), Wizard of Oz) into a design process, to test, explore and communicate ideas. In another line of research, interaction design engages with the concepts, frameworks and language of the performing arts to better understand its object: interactions of people and designed things (Benford et al., 2009). Our focus in this chapter is closer to this second, analytical line.

Considered from the perspective of everyday practice, co-performances are the doings of people and technologies. They are a sequence of doings performed in response to, and alongside one another. This sequential nature of action is a key feature of the performing arts as well. In a (theatrical) performance, these actions are tied together in a narrative of conflicts, crises, and resolutions. A vocabulary from the performing arts can be helpful in capturing aspects of these sequences that would otherwise be difficult to observe. It makes, for example, explicit the place and time of performances. It captures what people and technologies do, not in isolation, but also how they respond to one another, and how this response is guided by their respective roles and integrated know-how.

5.3.3. *The visual vocabulary of the screenplay*

Movies tell stories of dialogue, conflicts and resolutions. The screenplay (figure 5.1.) is a crucial device in the making of a movie. Written by screenwriters, this document provides director, actors and crew with a blueprint to follow during production (Trottier, 2014). Omitting unnecessary details, the screenplay prescribes the events on screen. It is formatted in a specific, and largely standardized way, capitalizing some text and applying different indentations. This visual layout enables readers (film agents, directors, actors) to recognize (at a glance): the length of a scene, involvement of different characters, time elapsed between shots, changes in location, balance between action and dialogue, and key points in a scene (Trottier, 2014, p. 97). Similar to earlier work (Benford et al., 2009), we draw on dramaturgy and its analysis of the structure of performance through space, time, plot and character.

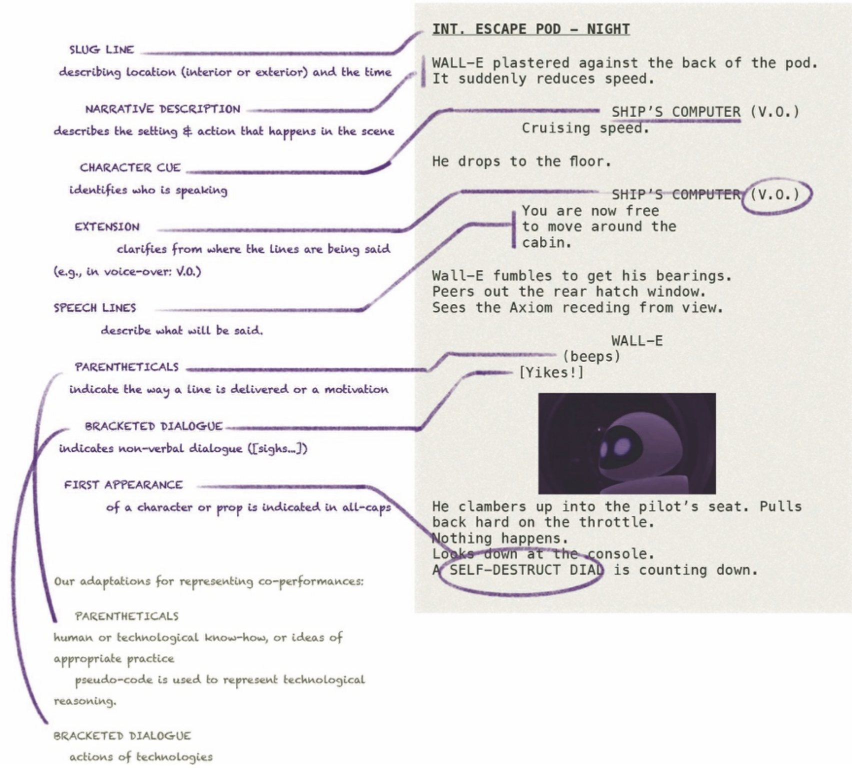


Figure 5.1. The visual vocabulary of the screenplay
(with text from the screenplay of Wall-E, by Stanton & Reardon (2008))

5.4. Ethnographic data in the visual vocabulary of the screenplay

This pictorial chapter makes use of the ethnographic data collected earlier in this research project. Chapter 2 describes the method for collection and analysis in more detail. Here, we selected (and sometimes reordered) statements about situations of crises and conflicts and the performers involved in them to build a chronological narrative. These make up, what we have suggested to be an enacted interface, which correspond to the crises and resolutions in a scene in a screenplay.

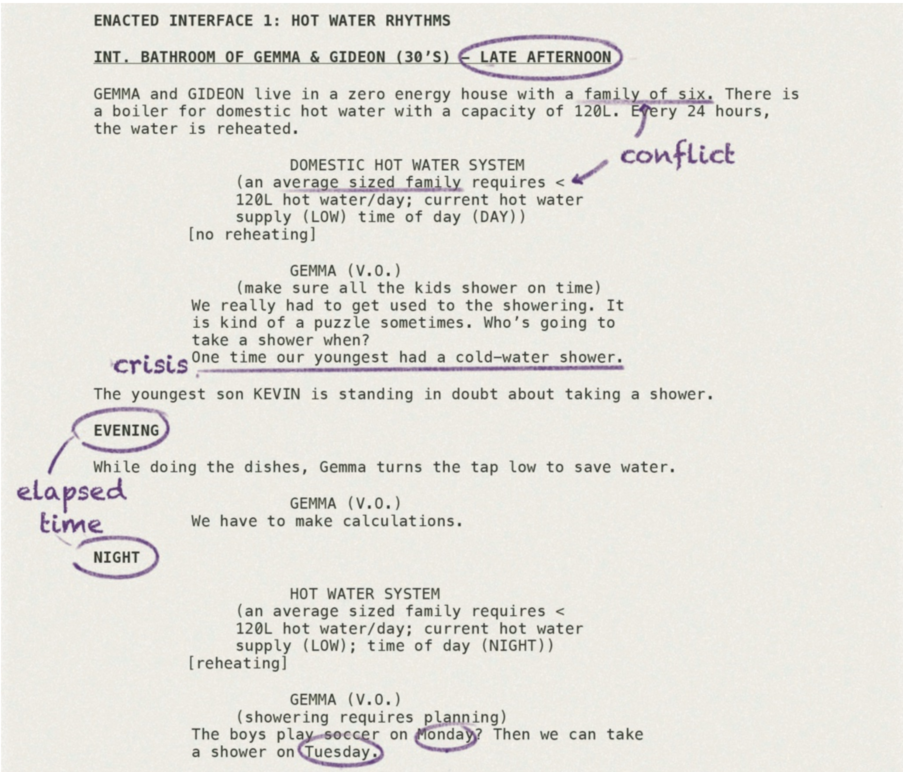
5.5. Representing and annotating the screenplay

In this section we present and read the resulting screenplays by annotating them. In our readings we recognize six distinct but related aspects of the enacted interfaces.

The quotes in the scenes below are directly translated from interviews. Parentheticals and technology actions are derived from our own earlier research and knowledge of the field, or from conversations with professionals involved with the households (e.g., social housing technicians). Stills from our video data were often, but not always, recorded at the same moment as the corresponding quotes.

5.5.1. *Responding to crises*

Similar to a scene in the typical screenplay, enacted interface 1 (figure 5.2.) presents a story arc, starting with a crisis. For Gemma it starts with a crisis in showering routines. This crisis, stemming from a conflict in know-how of appropriate practices (the projected size of a family living in this house and their needs), then branches out into different inconveniences (e.g., doing the dishes). This crisis is resolved through new routines involving new know-how (planning). In this description, the building requires an adaptation in everyday practices from the residents. It is through this adaptation of performances that a new matching is enacted. This new matching is apparent from the new 'routines' of the boiler which, with residents new showering routines, does not run empty.



ENACTED INTERFACE 1: HOT WATER RHYTHMS

INT. BATHROOM OF GEMMA & GIDEON (30'S) – LATE AFTERNOON

GEMMA and GIDEON live in a zero energy house with a family of six. There is a boiler for domestic hot water with a capacity of 120L. Every 24 hours, the water is reheated.

DOMESTIC HOT WATER SYSTEM
(an average sized family requires < 120L hot water/day; current hot water supply (LOW) time of day (DAY))
[no reheating]

GEMMA (V.O.)
(make sure all the kids shower on time)
We really had to get used to the showering. It is kind of a puzzle sometimes. Who's going to take a shower when?
One time our youngest had a cold-water shower.

The youngest son KEVIN is standing in doubt about taking a shower.

EVENING

While doing the dishes, Gemma turns the tap low to save water.

GEMMA (V.O.)
We have to make calculations.

NIGHT

HOT WATER SYSTEM
(an average sized family requires < 120L hot water/day; current hot water supply (LOW); time of day (NIGHT))
[reheating]

GEMMA (V.O.)
(showering requires planning)
The boys play soccer on Monday? Then we can take a shower on Tuesday.

Figure 5.2. Enacted interface 1

5.5.2. *Temporal synchronization*

The presented interface 1 does not take place in one delimited moment. Instead, it is set in afternoon, evening and night and even stretches across different days. Using the screenplay vocabulary to represent this interface, it becomes clear that events from the past and expectations of the future inform the dynamic of specific technology interactions. Bridging all these different moments (at first glance unrelated from a resident perspective) is the performance of the boiler system. By putting human and technological performances together in one scene, we have made their dynamics readable. By including the know-how integrated in technological performances in interface 2 (figure 5.3.), we can further explore the role of time in this scene. Enacting this interface involves the layering of multiple (human and technological) time scales. The time scale in which the light automation performs is in minutes, while Michael and Laura's performance spans multiple hours. The enactment of this interface involves a layering of time frames, purposefully synchronized to resolve the lack of light on the landing.

5.5.3. *Bodies*

Everyday practices of heating are (from a resident's perspective) to an important degree about realizing bodily comfort. The location of that body clearly matters to the appropriateness of technological co-performance of heating practices. In most cases it does not make sense for an automated heating system to heat unoccupied rooms. In interface 3 (figure 5.4.), the specifics of the technological performance (to which room temperature it responds), create a situation of crisis (working in a cold room). Julia and Micks response to this crisis then involves moving around the house. In this interface, the whole house is the stage, revealed by the sub headers indicating new locations. In addition, interface 3 highlights another embodied aspect of co-performing with this smart building. Enacting a match of residents and building involves careful embodied manipulation (wrist turns) and sensitivities (feeling cold). Performing with smart buildings is a performance where the details of delivery matter.

ENACTED INTERFACE 2: CO-PERFORMING A BEDTIME RITUAL

INT. LANDING AT MICHAEL & LAURA'S HOUSE – EVENING

MICHAEL and LAURA live in a terraced house with two children and a dog. BOB, their school-age son sleeps in an upstairs room, where a window above the door lets light from the landing in. This automated light turns off when no motion is detected. The detection can be turned off.

LAURA (V.O.)
(Bob needs to sleep well)
Our youngest really likes to sleep with the lights on at the landing upstairs.

Michael puts Bob to bed.

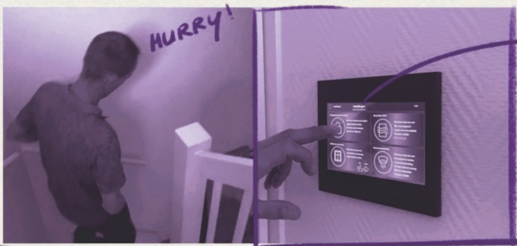
LIGHT AUTOMATION
(turn off when no-one present; motion detection (ON); motion detected (FALSE))
[timer starts that will turn light off after a few minutes]

know-how

LAURA
When we put him to bed, we set it to 'lock', so that the light stays on.

layer 1 (hours)

layer 2 (minutes)



lock lights while they're on

15 MINUTES LATER

Michael comes back downstairs, quickly puts light automation in lock mode on display in the living room.

LIGHT AUTOMATION
(detection (OFF))
[light stays on]

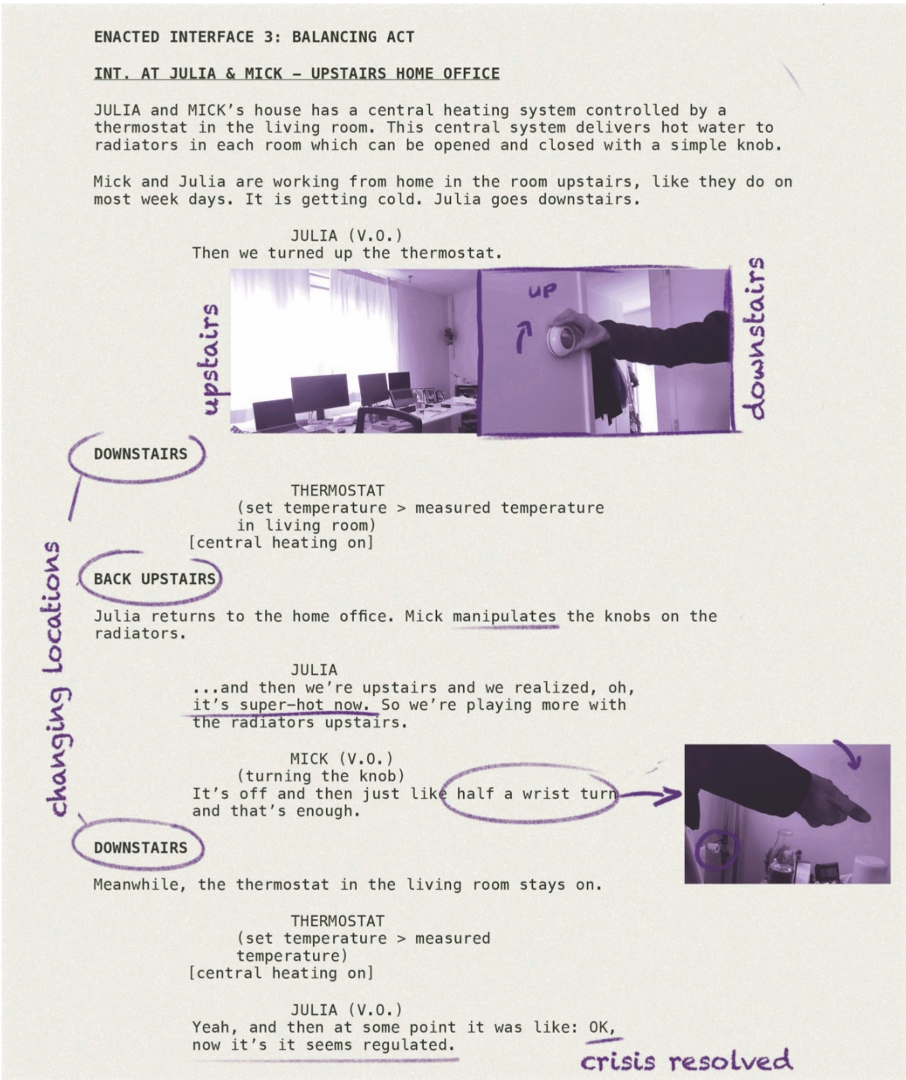
HOURS LATER THAT SAME EVENING

LAURA
And then when we go upstairs later, we put it back.

Michael goes upstairs, puts light in automated mode.

LIGHT AUTOMATION
(detection (ON); motion detected (FALSE))
[timer starts, turns light off]

Figure 5.3. Enacted interface 2


ENACTED INTERFACE 3: BALANCING ACT

INT. AT JULIA & MICK – UPSTAIRS HOME OFFICE

JULIA and MICK's house has a central heating system controlled by a thermostat in the living room. This central system delivers hot water to radiators in each room which can be opened and closed with a simple knob.

Mick and Julia are working from home in the room upstairs, like they do on most week days. It is getting cold. Julia goes downstairs.

JULIA (V.O.)
Then we turned up the thermostat.

DOWNSTAIRS

THERMOSTAT
(set temperature > measured temperature in living room)
[central heating on]

BACK UPSTAIRS

Julia returns to the home office. Mick manipulates the knobs on the radiators.

JULIA
...and then we're upstairs and we realized, oh, it's super-hot now. So we're playing more with the radiators upstairs.

MICK (V.O.)
(turning the knob)
It's off and then just like half a wrist turn and that's enough.

DOWNSTAIRS

Meanwhile, the thermostat in the living room stays on.

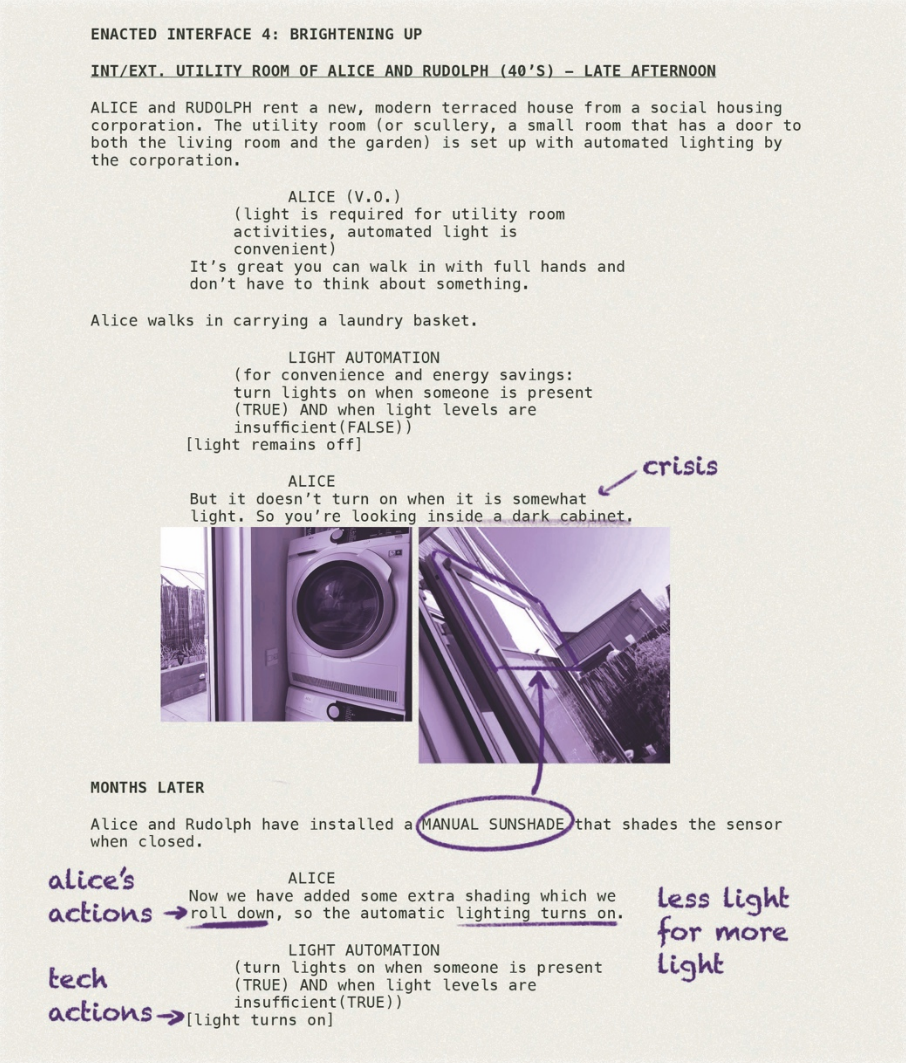
THERMOSTAT
(set temperature > measured temperature)
[central heating on]

JULIA (V.O.)
Yeah, and then at some point it was like: OK, now it's it seems regulated.

Figure 5.4. Enacted interface 3

5.5.4. *Props*

In interface 4 (figure 5.5.), the enactment involves not just the resident and the smartness in the building. Instead, for Alice and Rudolph, resolving the crisis of a dark utility room involves the installation of a material device, a manual sunshade. This material device is not automated, and thus, in a sense, less ‘smart’ than building and residents. However, it is in an important sense part of both human performances (being closed by Alice) and technological co-performance (blocking sensor readings). The sun blocking shade is in itself not enough as the interface or the resolution of the scene, but it becomes a part of the matching in co-performance (being rolled down), and thus plays a critical role in ‘making the interface work’.



ENACTED INTERFACE 4: BRIGHTENING UP

INT/EXT. UTILITY ROOM OF ALICE AND RUDOLPH (40’S) – LATE AFTERNOON

ALICE and RUDOLPH rent a new, modern terraced house from a social housing corporation. The utility room (or scullery, a small room that has a door to both the living room and the garden) is set up with automated lighting by the corporation.

ALICE (V.O.)
(light is required for utility room activities, automated light is convenient)
It’s great you can walk in with full hands and don’t have to think about something.

Alice walks in carrying a laundry basket.

LIGHT AUTOMATION
(for convenience and energy savings: turn lights on when someone is present (TRUE) AND when light levels are insufficient(FALSE))
[light remains off]

ALICE
But it doesn’t turn on when it is somewhat light. So you’re looking inside a dark cabinet.

MONTHS LATER

Alice and Rudolph have installed a MANUAL SUNSHADE that shades the sensor when closed.

ALICE
Now we have added some extra shading which we roll down, so the automatic lighting turns on.

LIGHT AUTOMATION
(turn lights on when someone is present (TRUE) AND when light levels are insufficient(TRUE))
[light turns on]

Figure 5.5. Enacted interface 4

5.5.5. Cameos

The format of the screenplay enables the recognition of new appearances. In interface 5 (figure 5.6.), the dog is critical for Louise in understanding technological performances and performing with the under-floor heating. Different from the auxiliary role of the manual sunshade in interface 4, the dog is herself a performer on the scene. She performs practices (drinking, warming up) which are meaningful to herself. They are also meaningful to the matching of Louise's performances (of heating and placing carpets) with the co-performance of heating by the smart building. In this way, the dog's performances and Louise's performances become entangled.

ENACTED INTERFACE 5: A DOGS GUIDE TO HOME COMFORT

INT/EXT. AT LOUISE (70'S) – EARLY MORNING

LOUISE lives with her dog DAISY in a terraced house. On the ground floor, this house has under floor heating. When Louise moved into this house, this under floor heating did not work right away. But then, on a cold morning the repairs finally start to have an effect.

Daisy is released from the dog crate in the living room where she sleeps.

DAISY (DOG) ← first appearance
(air is much warmer, thirst)
[runs to water]

LOUISE (V.O.)
What was really funny, when she came out of the dog crate, she immediately ran for the water. She normally never does that, so yeah, I think she was thirsty.

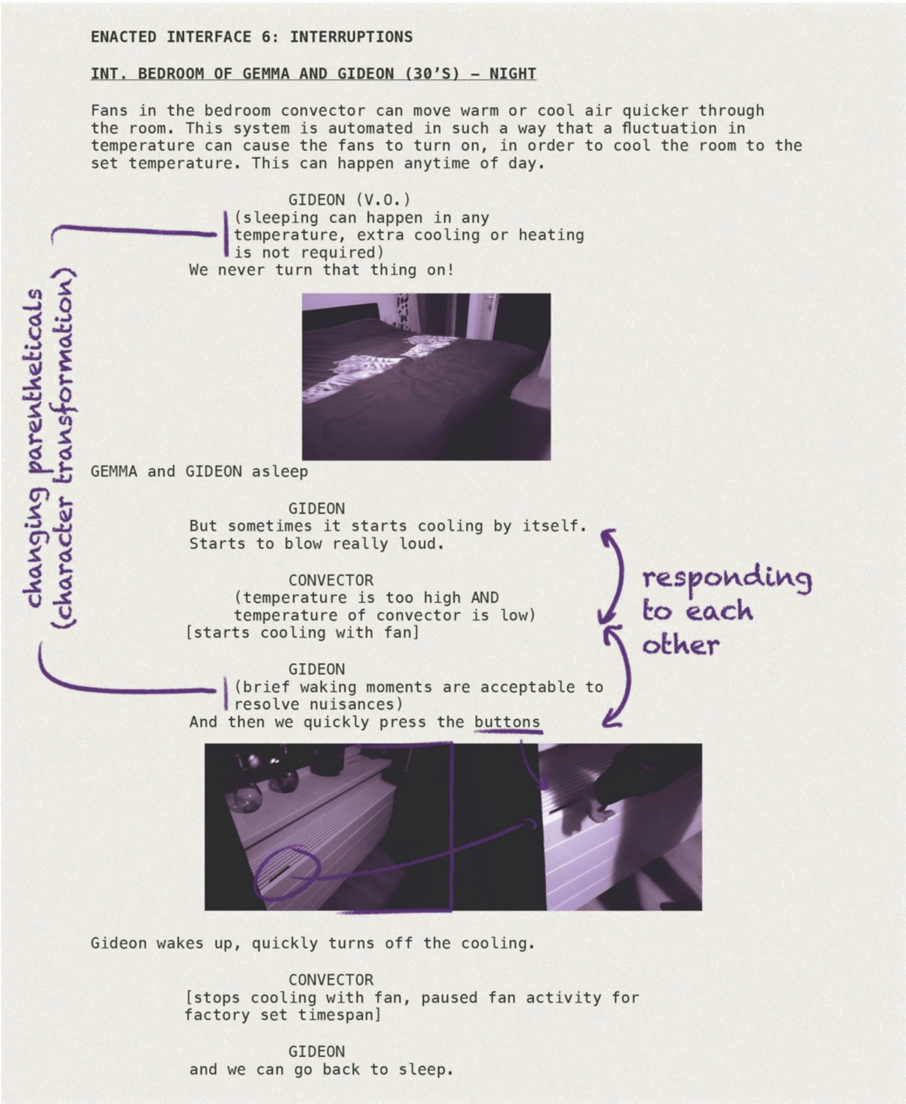
LATER, AFTER WALKING DOG

DAISY
(relaxed, but cold body)
[finds warm spot to lie down]

Daisy's behavior tells Louise where the under floor heating pipes are located. Since, she has shuffled around the living room without shoes to more precisely tell where to be for the most warmth.

LOUISE (V.O.)
Yes, the dog was lying down around this spot.

Figure 5.6. Enacted interface 5



ENACTED INTERFACE 6: INTERRUPTIONS

INT. BEDROOM OF GEMMA AND GIDEON (30'S) – NIGHT

Fans in the bedroom convector can move warm or cool air quicker through the room. This system is automated in such a way that a fluctuation in temperature can cause the fans to turn on, in order to cool the room to the set temperature. This can happen anytime of day.

GIDEON (V.O.)
(sleeping can happen in any temperature, extra cooling or heating is not required)
We never turn that thing on!

GEMMA and GIDEON asleep

GIDEON
But sometimes it starts cooling by itself. Starts to blow really loud.

CONVECTOR
(temperature is too high AND temperature of convector is low)
[starts cooling with fan]

GIDEON
(brief waking moments are acceptable to resolve nuisances)
And then we quickly press the buttons

Gideon wakes up, quickly turns off the cooling.

CONVECTOR
[stops cooling with fan, paused fan activity for factory set timespan]

GIDEON
and we can go back to sleep.

Figure 5.7. Enacted interface 6

5.5.6. Learning

In the screenplay, parentheticals allow us to recognize the know-how of characters involved in their actions. In interface 6 (figure 5.7.) the parentheticals motivating Gideon's speech lines are changing over the course of the scene. Where Gideon's first response (never intending to interact with the convector) indicates a flexibility towards the temperature in the bedroom and a lack of interest in heating this room, his second response involves an acceptance of nuisance. Like movie characters and their journey of transformation from resistance to acceptance, this can be described as a form of learning. This enacted interface is Gideons adaptation of routines and know-how to automated systems, and in this way his acceptance of their leverage in shaping everyday life.

5.6. Reflections

In this chapter, we have represented and annotated ethnographic data from a study of 11 households living with smart buildings. Our analysis focused on conflicts between what residents do and find appropriate and what technologies do, and how these conflicts are resolved through the enactment of new interfaces in the use phase. Using this visual vocabulary revealed that these enacted interfaces: respond to crises (1), involve time (2), and bodies (3); involve props (4) and cameos (5); and involve learning as part of the resolution (6). In this section, after reflecting on our use of the screenplay, we conclude that taken together, these aspects form the starting points for a way of thinking about interfaces.

5.6.1. The screenplay for reading co-performances

In this chapter, we found that the screenplay turns out to be a novel effective vocabulary for reading the interfaces. Our own data from smart buildings, including varying scales of time and place, lends itself well to representing enactments. This vocabulary and its associated dramaturgical approach offers a range of sensitizing concepts (such as characters, props, and time) which we hope makes designers aware of enacted interfaces, in addition to or replacing the ones designed in the technologies.

Furthermore, this vocabulary connects the concept of co-performance and enacted interfaces with smart technologies to a wide range of different interpretations and readings from the performing arts which we have not elaborated here. Future work could draw on concepts like stage (Goffman, 1974), transitions (Benford et al., 2009) and spectators (Sauter, 2004).

The screenplay could be further adapted as a tool not only for analysis, but also for design. In a parallel to the widespread use of storyboards (van der Lelie, 2006), roleplaying (Boess, 2006), and scenarios (Brandt & Grunnet, 2000), this has several potential benefits. It might enable designers to express, and document envisioned enacted interfaces. It might also help anticipation and inquiry into 'what might be' and thus help designers identify opportunities, potential challenges, and issues early on.

There are also limitations to the screenplay. As a representation it excludes many aspects. In our case, for example, we have not engaged with the many (corporate) interests and interdependencies introduced when technologies are connected to the internet (Redström &

Wiltse, 2019). Finally, when used for anticipation, the screenplay is inherently limited in predictive power, as performance is always contingent upon the situation.

5.6.2. *Enacted interfaces and interaction design*

Reading enacted interfaces through the vocabulary of the screenplay raises questions for research and design. From a perspective of co-performance, situated interactions are hard to predict and contingent upon the many factors (e.g., cameos and props) present in everyday life where residents live with smart technologies.

While the know-how integrated in the performances of smart technology often makes sense from a generic point of view (e.g., average daily needs of domestic hot water), our reading reveals that this reasoning led to crises of routines. Thinking about enacted interfaces as resolutions to these crises might be helpful in coming up with different forms of technologically-mediated 'responsiveness' (Giaccardi & Redström, 2020) (e.g., technologies that learn in use).

It appears that use time (i.e., the period when the technology is used in everyday life, in contrast to design time) is critical to enacting interfaces. It takes time for residents and smart building to work out new matches, and get further entangled. This suggests a more active role for designers after design time; helping, guiding and learning from newly enacted interfaces.

While crises in everyday routines appear to be good starting points for the enactment of new interfaces, they also present nuisance to the residents. There might be a way to engender crises in a way that is productive, while being less distressing. For example, a boiler could introduce a minor crisis in routines by only slightly lowering water temperature when coming close to the limits of domestic hot water, rather than creating larger crises when the boiler runs completely empty.

5.7. Conclusion

In this pictorial chapter, we have proposed the novel visual vocabulary of the screenplay. We have represented and annotated enacted interfaces in the co-performance of residents and smart buildings in this vocabulary. We hope that this serves a conversation about the roles, capacities, and appropriateness of the technological co-performances that we design (for), particularly in the domain of automated and connected systems that are present in everyday life.

6 REPRESENTATION 2: DESIGN SPACES[29]

In the previous chapter, we argued for design research to consider the *temporal dimension* and *ideas of appropriateness* in everyday practices. In our discussion in chapter 2, we also highlighted another aspect of this conceptualization. We argued that our more-than-human conceptualization positions the act of designing also outside practices of professional design, and sees it as a shared accomplishment of human users and technologies in the use phase.

This chapter responds to a need for representing and articulating these shifting boundaries of *capacities to design*. I propose visualization of design spaces of designers, users and technologies. Like in chapter 2, I connect this argument to narratives around smart technologies. After discussing how present technological developments and new understandings blur categories of design, use and artifact, I use visualizations of design spaces to highlight some contours in this blurred situation. These visualizations show that boundaries to design spaces are (among other factors) formed by what is considered *appropriate practice*. This chapter also presents three conceptual smart thermostats as thought experiments[30]. The developed way of visualizing might benefit design research in analyzing and anticipating the design capacities of users and technologies in everyday practices in transitions. Operationalizing the design capacities as relevant dimensions of everyday practices with technologies, and developing them in a design methodological proposal, addresses research question 3 of this dissertation.

[29] This chapter is based on a paper published as: van Beek, E. (2024) Contours in Blurred Design Spaces: More-than-Human Participation of Artifacts in Design-in-Use, in Gray, C., Ciliotta Chehade, E., Hekkert, P., Forlano, L., Ciuccarelli, P., Lloyd, P. (eds.), *DRS2024: Boston*, 23–28 June, Boston, USA. https://doi.org/10.21606/drs.2024.443 For consistency, I have made some minor edits with reference to work done earlier, which is also reported in this dissertation. I have also clarified concluding sentences regarding future work.
[30] To be clear, both in the context of this chapter and for the broader purpose of this dissertation, these thermostats should not be considered product proposals, but tools for thought. For concrete proposals with benefit to transitions, see the socio-technical innovations listed in chapter 4.

6.1. Introduction

Contemporary design practices increasingly revolve around so-called smart and algorithmic technologies that act, design, and create new possibilities, even after they are delivered. A human-centered design approach does not reflect these complex interdependencies and capacities for action (Coulton & Lindley, 2019). In response to this, more-than-human design approaches question agency and boundaries at the intersection of humans and nonhumans (Coskun et al., 2022). This means that design 'makes explicit and contestable the decisions that are delegated from everyday practice to development practice' (Giaccardi & Redström, 2020). This chapter contributes to this necessary 'critical and creative conversation' by discussing emerging relations between everyday practice and design or development practices, and by introducing and analyzing three critical design concepts, responding to these developments in a poetic and playful way.

This chapter takes as a context the automated and connected technologies increasingly present in everyday life. In smart buildings, for example, residents and homeowners implement motion-controlled lights, smart thermostats, and connected door locks. These technologies are not just 'used' by people, but perform everyday life together with residents in *co-performances* (Kuijer & Giaccardi, 2018). These co-performances are dynamic, they develop through crises of everyday routines and through conflicts between what people and technology consider appropriate. In this dynamic situation, new practices are developed: new ways of performing everyday life together with technology that were not expected by designers developing these technologies. These creative activities lead to a local fit, and the acceptance or domestication of new technologies. In this chapter, I understand these newly developed practices as forms of design-in-use (Botero et al., 2010; Kuijer et al., 2017).

In response to technological and environmental transformations, design research has started to adopt perspectives from studies of science and technology, in particular feminist new materialism and actor network theory. These perspectives add nuance to essentialist understandings of humans, technology and nature and have led to a call for more-than-human design insights and practices (Forlano, 2017). Recent theoretical work in design research has emphasized that the activity of design is a relational activity, that does not just include human designers but also non-human beings and materials (Wakkary, 2021). This emerging stream of posthumanist design research aims to go beyond essentialist understandings of humans as creative actors, and instead considers the designer an assembly of humans and non-humans, and things (or artifacts) as partners in design (Giaccardi, 2020).

Both conceptual frameworks – design-in-use and posthumanist design – blur the previously stable categories of design and use, and designer and designed. Although these topics are receiving increasing attention in design research, much of design discourse remains firmly grounded in a conception of design as found in industrial design and production. In this understanding of design (known as human-centered design), a human designer creates a product for a problem that users might have. This design would then be produced and subsequently used by users as intended by the designers.

This chapter responds to this conventional view, and further articulates emerging ideas to make them recognizable by design researchers (and practitioners) who are less involved in theoretical developments. I adopt a critical design approach to draw attention to design-in-use and to more clearly articulate how objects could (and already do) participate in design-in-use, and to uncover some critical issues that should be foregrounded in these discussions. I ground my discussion in the concept of design space and make use of the framework of co-performance (Kuijer & Giaccardi, 2018). Later in this chapter, I introduce three smart thermostats: conceptual artifacts which participate in design-in-use.

6.2. Blurred categories of design and use

In this section I first expand on the notions of *design-in-use* and *co-performance*. I then highlight the *role of artifacts*. After that, *design space* is introduced as an analytical concept that can help describe and get a grip on these new notions. I compare *design spaces* with and without considering notions of *design-in-use* and the *role of artifacts*.

6.2.1. Design-in-use

It has long been recognized that a variety of people, through everyday activities, creatively appropriate, shape and domesticate new technologies. While going under different guises (appropriation, domestication, etc. (Eglash, 2004)), the term that has found most traction in design research is *design-in-use* (Botero et al., 2010; Ehn, 2008). Other terms are everyday design (Wakkary & Maestri, 2007), and non-intentional design or design by use (Brandes et al., 2013b). A mundane example is the repurposing of a chair (designed for sitting) by standing on it to get something from a high shelf. The key insight from these studies is that creative and design-like activities happen, not just in the design studio, but also in mundane and domestic contexts. The other relevant insight is that this leads to relations between artifacts and end-users that are not planned for in the design situation.

6.2.2. Co-performances and appropriateness

Design research, especially where it deals with domestic technologies and energy, has long drawn on social practice theory and related sociological work (Ingram et al., 2007; Shove et al., 2007). Recently, this perspective has been applied to smart home technologies. The concept of *co-performance* emphasizes that these automated technologies perform everyday life together with people. These technologies (such as smart thermostats or automated lights) act alongside and without the direct involvement of humans, and should thus be considered co-performers of practices (Kuijer, 2019; Kuijer & Giaccardi, 2018).

In co-performance, everyday practices involve an idea of appropriate forms of action (Reckwitz, 2002). Human performers performing practices (e.g., laundry) judge what is appropriate practice ('what is clean laundry?'). For artificial co-performers this notion of appropriateness is embedded in their specific embodiments and automations (for example 'washing machine programs') (Kuijer, 2019). What is appropriate performance for artificial co-performers is based on the ideas that designers have about appropriate practice, applied in the design process. Appropriateness, in other words, refers to that which is socially and culturally acceptable in specific situations and to specific actors.

What is appropriate is situated and contested. In the ethnographic work reported earlier in this dissertation, we found that residents improvise and experiment with new technologies and change their practices through crises and conflicts. They develop their own ways of interacting with these technologies, such as developing new routines of opening windows to regulate heating, or temporary tricking of light sensors.

6.2.3. Design-in-use involves not just humans but also artifacts

As already briefly noted in the introduction, there is an increasing acknowledgement that human designers are not autonomous in making things. Instead, design is a collaborative accomplishment of humans and non-humans (Wakkary, 2021). Especially when dealing with networked and increasingly agentive capabilities of modern technologies, we need an understanding of humans and technology which emphasizes relations, technological agency and assemblages composed of humans and non-humans (Giaccardi & Redström, 2020). In these understandings, the designer is an assembly of humans and non-humans. To better articulate this relationality, recent research has emphasized and more deeply explored the specific roles taken up by non-humans when they participate in design (Giaccardi, 2020; Giaccardi et al., 2020; Hee-jeong Choi et al., 2020).

Critically, we can translate this observation of design as a more-than-human accomplishment from the design studio to the domain of design-in-use. While an in-depth discussion is beyond the scope of this chapter, existing work and the previous chapters have highlighted that artifacts design in use. In use situations as well, design activities are not just the actions of human users improvising and adapting, but involves materials and artifacts (Kuijer et al., 2017, p. 18). In the rest of this chapter, I approach, and further develop, design-in-use as a collective accomplishment of the material resources available and of human skills and goals.

6.2.4. Design space through the lens of co-performance

To deal with and better describe various situations and opportunities for design, earlier work has engaged with the analytical concept of *design space* (Westerlund, 2005). Botero et al. describe design space as "the space of potentials that the available circumstances afford for the emergence of new designs" (2010). This is a helpful definition, but it also leaves certain questions unanswered, for example: what do we mean by *space*? And what is *design* in this definition? By working further with this concept, the authors provide some guidance on how to interpret these. For example, when it comes to what 'designs' could be, they indicate that design space does not just include an artefact, but also social practices and agreements. This suggests that a *design* refers to one instance in the set of possible relations between, on the one hand, a human (user) and what they do, and on the other hand a technology or artifact. Using the framework of co-performance introduced earlier, I can specify this relation somewhat more to mean: a co-performance which involves human and artificial performances.

The other word, *space*, seems to be used by Botero et al. primarily as a way to demarcate what is inside and outside the range of possibilities that enable the emergence of these designs. This space has boundaries, and inside are the possible designs. This space is constructed, they argue, through the presence of different stakeholders, tools, technologies, and materials, as well as through social processes and agreements. This indicates that design space is not (only) demarcated by material limitations (i.e. which kind of interactions are enabled by the physical features of this product?), but also by what is socially and culturally acceptable. In a vocabulary informed by social practice theory and co-performance, this idea of acceptability would be referred to as 'appropriateness' (Kuijer et al., 2017; Kuijer & Giaccardi, 2018).

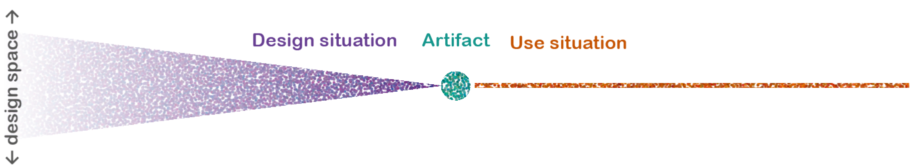
Thus, for the scope of this chapter, I work with this definition: *design space* refers to: *the range of possible and appropriate co-performances of people and technology*. Note that this is a relational and situated definition: it depends on physical features of the situation, on social and cultural circumstances, and on how humans and technologies interact with each other and with these circumstances.

6.2.5. Conceptions of design spaces and the role of artifacts

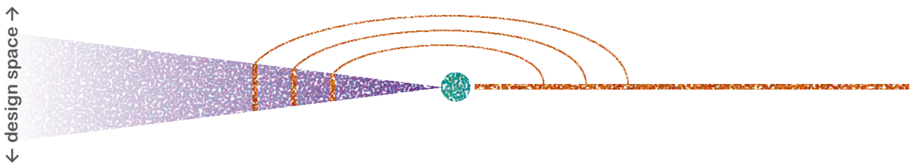
We can apply this concept of design space to various understandings of how design and use are related. In the introduction of this chapter, I have described a conception of design and use as espoused in traditional industrial design and human centered design. There, the design space (the range of possible new relations or co-performances) is broad in the design situation, when various options are considered by professional designers. Once the product is put in production, however, the design space converges to one relation: that of the designed use (figure 6.1.a.). In this conception, design is a stabilizing process towards one option (Giaccardi, 2019). (It should be emphasized that this is a way of thinking about design and use, not what actually happens. Even in the age of industrial production, artifacts were always appropriated in un-designed ways.)

In response to the limitations of this converging nature of design, designers and researchers have developed several approaches and movements. There is a wide diversity in motivations (political, pragmatic) and styles, but these approaches are generally recognized as co-design or participatory design (Sanders & Stappers, 2008). Co-design makes a connection between the design and use situations (figure 6.1.b.). Here, users and their practices and wishes are brought into several stages of the design process to help create an optimal fit between artifact and (future) practices of use. Still, the design space (the consideration of different options) remains open only until the product is put in production and launched. Botero and Hyysalo describe this as the model of 'start wide and focus to the product' (2013).

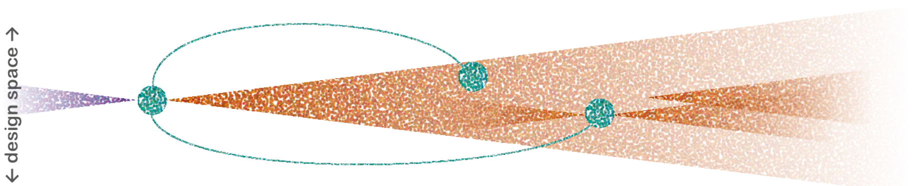
The shape of the design space takes a radically different form in a conception of the design process that includes *design-in-use* (figure 6.1.c.). Here the design space remains open or is further expanded once a product is delivered. The artifact can be used or engaged with in many ways, and might even be adapted or transformed in the process. Different relations (and co-performances) are possible. In fact, the design space remains in constant flux as new designs 'tend to seed further evolution' (Botero & Hyysalo, 2013).



a. Traditional industrial design and production: the design space narrows down to a specific (imagined) use of the artifact



b. Co-design: use situations are brought into the design process to help narrow down how an artifact will be used



c. Design-in-use: new possibilities are discovered in the use situation, sometimes transforming the artifact in the process

Figure 6.1. Different conceptions of design space in design and use situations (note that the x-axis does not indicate chronological time, but rather an assumed causal flow)

6.2.6. Blurred categories

In the conceptions of design and use portrayed above, the artifact plays a fundamental role as either, the endpoint of a converging design space (in industrial and co-design), or as the object around which new relations emerge in use situations (in design-in-use).

However, these earlier studies have been primarily concerned with 'what *people* do' (Botero et al., 2010) [emphasis added], be it designers or users. This has left the participation of the artifact out of the picture. But as we have seen above, a perspective of co-performance highlights design as not just an activity of humans, but as an accomplishment of both humans and things. If we take this idea seriously, the dichotomies between designer and user, design and use, and designer and designed artifact no longer hold. Taking a more-than-human approach and looking at (automated) artifacts as co-performers, artifacts become participants in design activities in use, with their own design space of appropriate co-performances.

This observation raises questions about the relationships between design, use, and the role of the artifact. Specifically, in the rest of this chapter, I want to investigate how the presence and active involvement of the artifact as a co-performer reshapes design spaces. Thus, my primary focus in the remainder of this chapter is to provide clarification and insight into these somewhat blurred categories (figure 6.2.). I do not aim to definitively resolve them but to highlight critical issues that deserve attention in discussions related to design-in-use, particularly when considering the active role of non-humans.

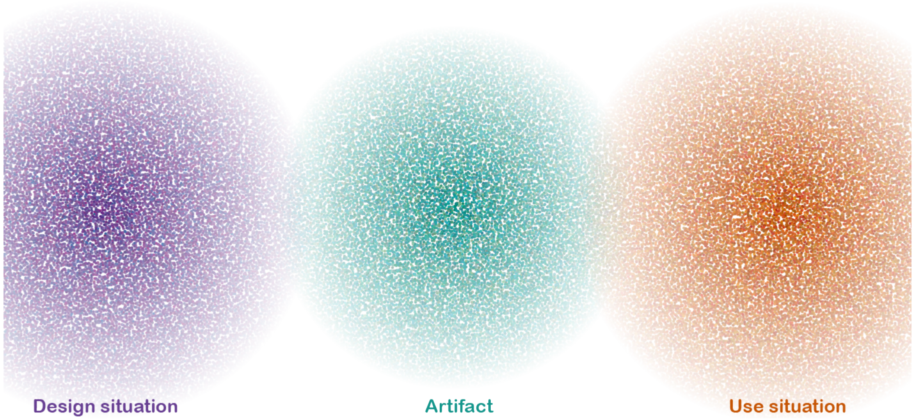


Figure 6.2. A blurry conception of design space, indicating the question how to conceptualize artifacts participate in design-in-use

6.3. Critical design by materializing metaphors

Critical design is a creative practice that aims to provoke critical thinking and dialogue by using design as a medium (Bardzell & Bardzell, 2013). It is a way of raising questions, challenging assumptions and articulating issues, in particular in relation to emerging technologies (Dunne & Raby, 2013). The products of critical design are not meant as serious product propositions (and also not as predictions about the future) but as thought experiments (Barendregt & Vaage, 2021) or props (Dunne & Raby, 2013). The way I make use of critical design in this chapter is best described as a way of *making definitions through design* in order to contribute to design discourse (Redström, 2017, pp. 118–119). Concretely, this means that I (further) define my view on 'artifacts participating in design-in-use' by making it into a design concept, which I present in visuals.

Metaphors are literary devices or figures of speech that compare or relate two things in order to see them in a different light (Cila, 2013). Metaphors have proven to be useful ways of investigating the materiality and implications of new technologies (Benjamin et al., 2023; Cila et al., 2017).

The metaphors I chose are *framing*, *tinkering* and *scripts*. These metaphors and figures of speech are already present in discourse in design and design research. As such, I expect them to be recognizable and familiar to the audience of my critical designs. They might even be so familiar that they are barely recognized as metaphors or figures of speech. I engage with these metaphors, not on their own (more serious) terms, but in a somewhat poetic and playful way.

I chose these specific metaphors strategically to highlight a specific aspect. Typically, *framing*, *tinkering* and *scripts* are used to describe (parts of) design activities. I apply them to what artifacts do. In other words, I transfer a concept from one domain (design activities by designers) to another, closely related domain (design activities by artifacts). This imaginative move renders the artifacts in the design concepts explicitly and visibly as a participant in design activities.

By using these metaphors in a critical design approach and materializing them in artifacts I attempt to 'make them strange again'. My point is not to say that products should be designed this way. I also do not want to make the point that every existing artifact engages in design activities in the way I present below. Rather, my point with these concepts is to think through (the implications of) my view on design, artifact and use presented above, and to draw attention to their connections.

I selected these specific metaphors in part because of their generative value (i.e., I was able to translate them in a design concept) and in part because of their fit with my understanding of design and use as *performance* which also figured in the previous chapter (Macaulay et al., 2006; Schechner & Brady, 2013).

6.3.1. The one that frames

The idea of 'frames' has been credited to Bateson (1972) and theorized and developed originally in sociology and performance studies (Goffman, 1974). It was introduced by Schön in the context of architectural design (Schön, 1984), and in recent years it has been productively applied in thinking about design activities and beyond (Dorst, 2015).

A 'frame' is a construct that brings coherence to how a situation (objects or events) is understood (in terms of cause, effect, action possibilities, etc.). Frames are not objective, but 'social or rhetorical constructions' that allow different perspectives to be explored (Chandrasegaran et al., 2022). 'Framing' is the activity of setting situation boundaries, and selecting particular things and relations to pay attention to in design in order to solve a problem (Schön, 1984).

Bateson, in introducing the frame, draws on the analogy of the 'picture frame'. A picture frame indicates to viewers that they should "attend to what is within and not to what is outside" (1972), and it "tells the viewer that he is not to use the same sort of thinking in interpreting the picture that he might use in interpreting the wallpaper outside the frame".

Inspired by this line of thinking, I created the design concept *FrameShifter* (figure 6.3.). This smart thermostat collects data from different sensors in the home, gathers this data together into a *situation*, and then uses literal picture frames to frame this situation to residents in different ways. A text on a screen allows a human user to look at this situation (for example: a heated but unoccupied room) as something to solve, to make use of, etc. When a new situation is detected, the *FrameShifter* randomly selects one of the frames.

The *FrameShifter* participates in one specific part of design activity: framing. It doesn't go so far as to propose any new solutions, but rather contributes to new lines of thinking. It can surprise and disrupt sedimented ways of thinking about energy use and indoor climate, in order to broaden the range of possible ways of dealing with this situation (for example, not just ignoring or resolving it, but making use of the opportunities presented by situations).

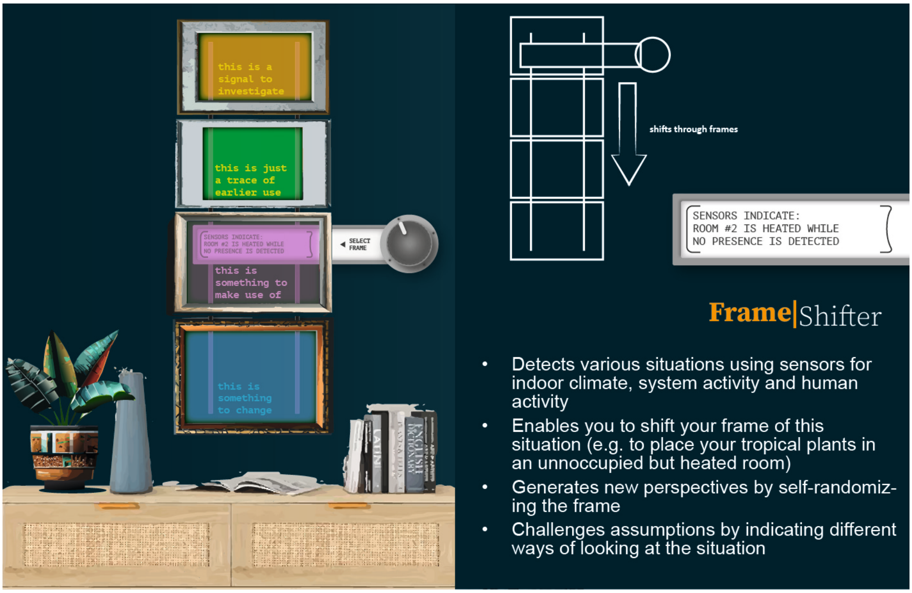


Figure 6.3. FrameShifter

6.3.2. *The one that tinkers*

Some say 'tinkering' is derived from the verb 'tink' to make a tingling sound, although many find that unlikely (Ekwall, 1936). In any case, the word 'tinker' used to refer to people who fix pots and pans, going from door to door, doing many kinds of minor work. In design discourse, the word is used to describe how people explore different solutions in an unstructured way. Tinkering means paying close attention when doing small experiments. It is a trial-and-error approach to problem solving, which simultaneously also leads to learning by the tinkerer. The tinkerer is seen as someone with a maker mindset, developing original material out of curiosity (Hatch, 2014). Often, the word is associated with repair, or localized solutions in the face of adversity and scarcity (Beniwal, 2020)

Tinkering is seen as a key feature of design (Reddy & Linde, 2016) especially in design education (Deniz & Akbulut, 2019). Tinkering is a way of arriving at a wide range of possible solutions, without settling early. It is also a way for design practitioners to get familiar with design materials and design space.

The concept of tinkering inspired the *tinkerTherm* thermostat (figure 6.4.) that tries out a wide range of different performances (or patterns of indoor climate control). This design concept, using self-learning algorithms, approaches each day as a new experiment. Each day is an opportunity, on the one hand, to learn more about the building and residents' co-performances (the 'design materials') and, on the other hand, a way to optimize its own performance (towards a 'design goal'). *tinkerTherm* acts like a designer getting a grasp on the situation and opportunities to intervene in this situation. Its algorithms are set up to both diverge and experiment with out of the ordinary performances, and to converge from time to time to a temporary optimal solution.

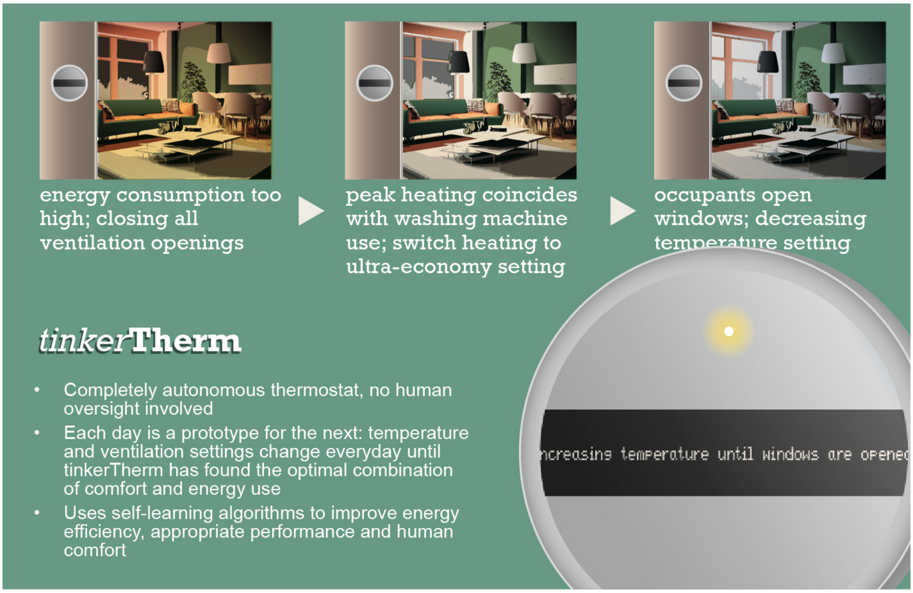


Figure 6.4. tinkerTherm

6.3.3. *The one that writes scripts*

The script is a way of defining what actors do in a movie or stage play. It forms a blueprint to follow during the performance. The concept of script has been famously appropriated in science and technology studies (Latour, 1992). Here, scripts refer to the 'framework of action' (Akrich, 1992) defined by the object. The object expects the user to act in a certain way (e.g., an angled seat surface enables a user to sit on a chair, and discourages standing). Depending on the form of a product, it permits and prevents certain courses of action. From an STS perspective, every designed product has a script, but scripting is not always obvious.

Scripts can be intentionally developed by the designer and are sometimes made explicit in design processes. In user experience design, for example, scripts are detailed in scenarios or storyboards (Ingram et al., 2007). Scripts can also be implicit, and part of cultural norms and views unconsciously held by the designer which are embodied in the product.

Following up on the previous chapter in which we used the textual and visual format of the script to represent co-performances, I developed a smart thermostat concept that writes and prints scripts. This *script_writer* (figure 6.5.), on the one hand, makes explicit which activities and tasks in managing indoor climate and energy use are performed by the thermostat and which by human actors (e.g., opening windows). On the other hand, it uses large language models to create variations on the initially designed scripts, both prompted (e.g., when residents indicate they expect guests) and unprompted (e.g., when it notices deviations from the original script). In this way, the *script_writer* participates in design-in-use like a designer; investigating patterns of use, and proposing variations on these patterns.

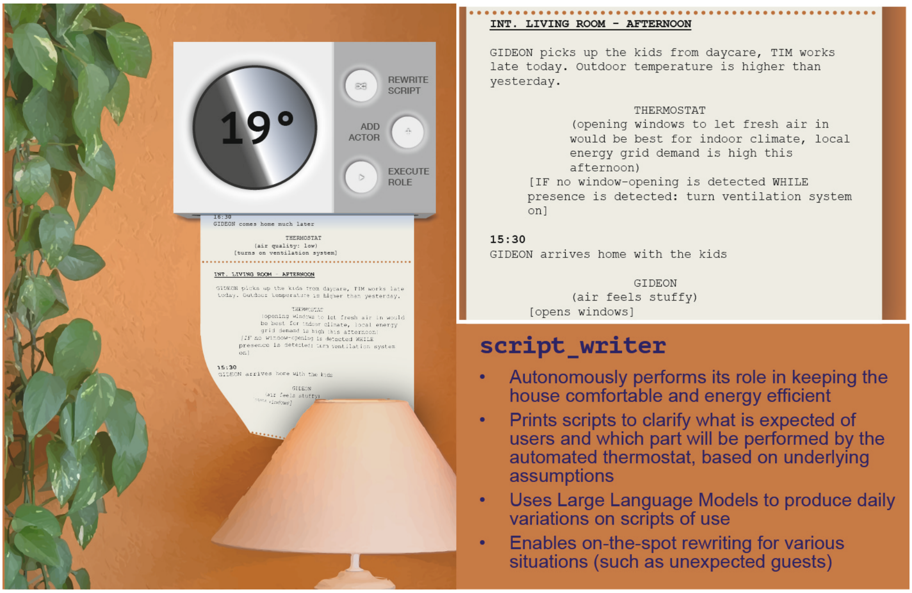


Figure 6.5. script_writer

6.4. Discussion: Contours in blurred categories

I presented three design concepts which participate in design practices in the use situation. To a certain extent, the design concepts, as critical designs, should speak for themselves, but they also invite further discussion. Here I aim to further reflect on the definitions I created through design, and what they entail for my understanding of design spaces and their transformations when we acknowledge and emphasize the participation of the artifact as a co-performer with its own design space. This reflection is based on my own insights in how these devices would function, and a first informal evaluation round of these concepts. I summarize these insights in four themes, and visualize them in a depiction of the design space in figure 6.6. In this figure, the purple area on the left indicates the design space of the design situation. The orange area coming from the right, indicates the design space of the use situation. And the circular turquoise shape indicates the design space of the artifact.

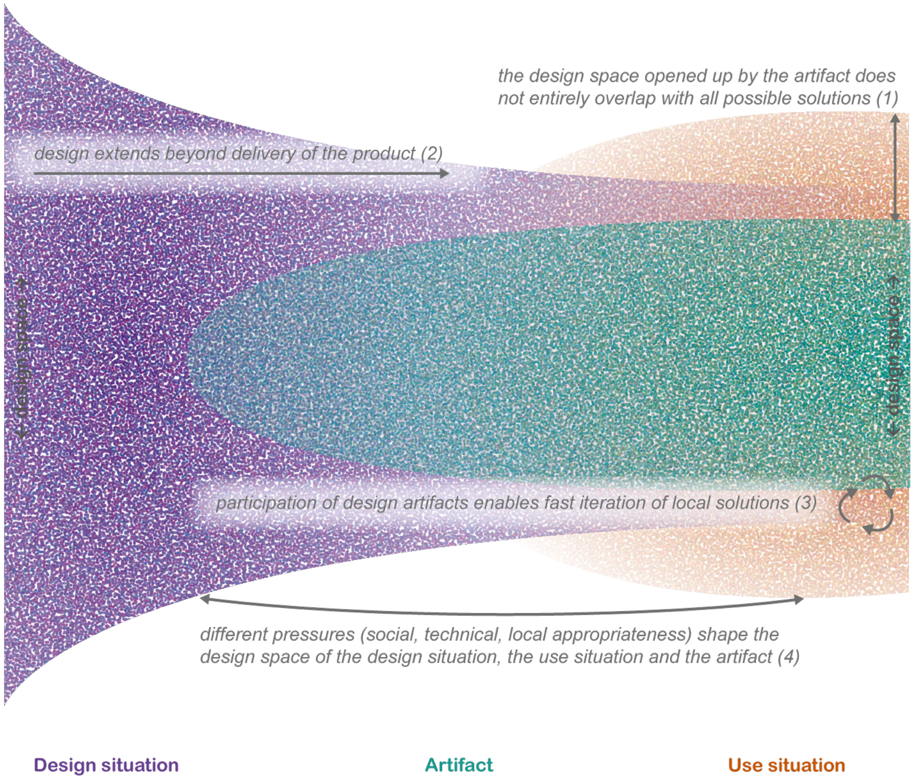


Figure 6.6. Some contours indicating the range of possibilities (i.e., design space) opened up in the design situation, through the artifact participating in design, and through the use situation. Numbers refer to sections in the discussion.

6.4.1. *New design spaces and overlaps*

In the introduction to this chapter, I have defined design space as 'that which is included in the range of appropriate co-performances of people and technologies'. The first insight to note here is that the artifact in these proposals has its own design space, distinct from design spaces in the design situation and the use situation. The *script_writer*, for example, can perform new co-performances of technologies and users which were not present or available in the design phase. Here, new ways of acting are suggested and carried out. This implies, that my conception of design space has to expand Botero and Hyysalo's mapping which only includes what is done by users and what is designed for by designers (2013). In my concepts, the artifacts themselves also have a range of possible co-performances or relationships. I have indicated this space in turquoise in figure 6.6.

Any design space is inherently finite. There is only a limited range of possibilities which are possible and appropriate in any given situation. This also applies to the design space of the artifact. The *FrameShifter*, for example, opens up a wide range of possible practices (new performances inspired by the framings of the situation), but in the end this device is limited to four frames. It should also be noted that the design space of the artifact does not overlap entirely with the design space of the use situation. One can for example easily come up with situations in which users appropriate the printed scripts of the *script_writer* in very different and undesigned ways (e.g., as notepaper or as a memento of a day in the past). This is what Fallan and others refer to as *de-inscription* (Fallan, 2008). I have indicated this possibility for undesigned appropriation by distinguishing the boundaries of the orange area from the turquoise area in figure 6.6.

For design practice this new design space signals an additional area of potential responsibility. Can designers be responsible for artifact performances they did not design for? If so, design practice must become not just anticipating of, but also responsive to new ways of use (or other types of relations) which might emerge in the use situation.

6.4.2. *Extending the design situation*

While each of the presented concepts is present in the use situation, they also remain connected to the design situation (or at least, their performance would benefit from such a connection). The *tinkerTherm* could come up with new and improved co-performances, but one can easily imagine how it could go off the rails. For example, its algorithm might get stuck in a local peak trying to optimize its performance, or it might not be able to deal with completely new situations (e.g., a house renovation).

Designers and design tools, when involved beyond the delivery of this artifact, could, together with users, prevent such a situation and shape the design space according to what is desirable and appropriate. Such an extension of design *beyond design* has been argued for also in other domains (Dorst, 2019; Ehn, 2008), while it is becoming increasingly possible with networked and computational artifacts (Giaccardi, 2019). This however also highlights how the agency and potential impact of designers and product developers is increasingly extended. This can be seen ‘in the wild’ when smart products are turned off remotely by providers when supposedly ‘misused’. This raises the important question of who gets to decide what is ‘appropriate use’ and if designers are equipped to take this decision (better than end-users).

6.4.3. *Local and fast iterations*

Design-in-use is a way of quickly and resourcefully adapting means to ends. This is often done impromptu and through short iterations. When artifacts participate in these iterations, they need to be responsive to local variations and to situations that change relatively fast (faster than cycles of design and use in industrial production). In the case of the *tinkerTherm*, these iterations happen on a day-by-day basis, while the *FrameShifter* moves from situation to situation. This means that design activities towards this end of the spectrum (in-use) are often quick explorations of or movements through the design space available. I have indicated this with cyclical arrows in figure 6.6.

6.4.4. *Pressures that shape design spaces*

I stated earlier that design spaces are limited by what is considered appropriate. These limitations are not the same for each actor and situation. In the *design* situation, the kind of solutions that a human designer comes up with is limited by what they consider fit with the goal of the product (e.g., reducing energy consumption), with other stakeholder goals, and with expected patterns of use. In the *use* situation (design-in-use), on the other hand, this appropriateness is considered primarily by the user and will thus be defined by ideas like ease of use, social expectations, and societal norms. Finally, the *artifact*, participating in design, has again a differently shaped design space. It enables certain co-performances and not others. The pressures acting on the artifacts' design space are primarily technical and material: Which co-performances are possible given the way this artifact functions and is programmed? Using large language models like *script_writer* will likely open up more possible co-performances than the four possible options in *FrameShifter*. I have tried to indicate these different limitations in figure 6.6. by representing the three design spaces in different shapes.

The lack of precise overlap between these design spaces indicates a disagreement about what is appropriate between designer and user. Users and designers have different goals and views of everyday practice. This highlights the political dimension of design spaces. Who gets to decide on the boundaries of appropriateness and how do we make sure that relevant voices are represented in this decision?

6.5. Conclusions

Automated artifacts as co-performers of practices participate in design in use. In this chapter have discussed how the participation of artifacts in design blurs categories of design and use. I have used and further developed the concept of design space informed by a framework of co-performance to highlight some contours in this blurred situation. I have done so by designing three design concepts for artifacts that make their participation in design-in-use explicit and visible.

The aim of these designs is to articulate issues and some initial implications by *making definitions through design*. This contributes to awareness and discussions of design-in-use and the role of artifacts that designers put out in the world. This research provides entry points for future research which could start with the role of the artifact. This research also informs the evolution of future design practices and education where designers can deliberately anticipate and respond to the design spaces for designers, users, and artifacts.

7 DISCUSSION AND CONCLUSION

In this discussion chapter, I reflect on how I addressed the main objective of this research by developing a conceptualization of changes in everyday practices with technologies as improvisation. I reflect on how this diverges from and complements human-centered design approaches. Furthermore, I reflect on doing interdisciplinary work and what design research has to contribute. Next, I reflect on further implications of the findings for research, for society, policy and technology development, and for design. I address some of the limitations of this work, suggest areas for future work, and end with concluding remarks.

7.1. Recap of this research

In the research reported in this dissertation, I investigated everyday practices with technologies in transitions. In chapter 1, I laid out the context and background and articulated the need for a conceptualization which might benefit the fields of design research, and other fields of knowledge concerned with transitions and technologies.

In chapter 2, I developed such a conceptualization of everyday practices with technologies in transitions. I developed it based on ethnographic research on these everyday practices, specifically with heat pumps in the Dutch energy transition.

I understand everyday practices as *co-performed*, indicating that humans and technologies perform everyday life together, with potentially *conflicting ideas of appropriate performance*. *Everyday crises of routine* form a critical part of how these co-performances are *reconfigured*. In short, changes in everyday practices with technologies in societal transitions are conceptualized as *improvisations*. I also introduce a new notion of *interface*, enacted in practice, rather than designed.

In chapter 3, I revisited the ethnographic research to explore how the developed conceptualization of everyday practices from a design perspective might contribute to challenges in transitions research. I identified three types of practice reconfigurations, which are necessary for, and have the potential to contribute to, the Dutch energy transition. These types are reconfigurations of *knowledge, routines* and *material*.

In chapter 4, I explored how the developed conceptualization might contribute to building science by creating an animated video, illustrating the proposed conceptualization, introducing it to heat pump supply side actors, and evaluating it with them through semi-structured interviews. I identified *ten possible responses* to improvisation from the technology supply side and *nine motivating factors* for choosing a response. I also propose socio-technical innovations connecting the supply side to everyday practices of use as sites of intervention for design.

In chapter 5, I introduced the design methodological proposal of the screenplay to represent and annotate improvisational co-performances. This vocabulary is proposed as an instrument to analyze and anticipate the *temporal dimension* and *underlying ideas of appropriateness* in everyday practices with technologies.

In chapter 6, I introduced a second design methodological proposal. The idea of design spaces is explored to visualize, analyze and anticipate the *design capacities* of designers, users and technologies, which are confined by what is considered *appropriate practice*.

Finally, in this discussion chapter, I first reflect on the main contribution of this dissertation and the research questions. I then draw out some implications of the findings for policy, technology development, and households. I address some of the limitations of this work and conclude with suggestions for future work.

7.2. Assembling a conceptualization of everyday practices with technologies in transitions for design

In the introduction of this dissertation, I raised the question how design might engage with technology uptake in transitions. I highlighted how the answer to this question depends on the way everyday practices are conceptualized. I identified a tension between efforts directed towards societal transitions and human-centered design, as these two contain opposing ideas about everyday practices. Human-centered design is about accommodating existing everyday practices and satisfying individual-human concerns (potentially making energy consumption as easy as possible). In contrast, in societal transitions, everyday practices change and align with other-than-individual-human concerns and societal goals. In this dissertation, I have addressed this tension (between human-centered design and efforts towards societal transitions) by developing a conceptualization of everyday practices, the implications of which could aid design practices in these transitions.

A conceptualization is an abstract, simplified view of the world that we wish to represent for some purpose (B. Smith, 2003). In part, the conceptualization developed here is an extension of already existing conceptualizations and theories. Most notably, it extends the idea of co-performance proposed by Kuijer and Giaccardi (2018) and builds on frameworks of theories of practice (e.g., Reckwitz, 2002; Schatzki, 2002; Shove, 2016) and more-than-human design (Giaccardi & Redström, 2020). These frameworks do not have a single ontology, but are strands in a loose group of theories, conceptualizations and ontologies of everyday life and technologies. Existing conceptualizations within this group are multiple, diverse and sometimes incompatible (Schatzki, 2016). Consequently, the work performed in this dissertation has been an exercise in assembling. Drawing on existing work, I brought together elements (objects, processes and relations) that differ in some respects. More-than-human design, for example, is not necessarily practice-oriented and has a broader idea of non-human agency than traditional theories of practice. But as the purpose of the conceptualization developed here is to propose actionable implications for designers, I have sought to bridge these different conceptualizations in a pragmatic way. Throughout the chapters, in particular in the discussions, I show that the developed conceptualization is at least ‘rationally sensible’ and ‘useful’ (Schatzki, 2016). ‘Rationally sensible’ means that convincing arguments and interpretations can be provided, and that the conceptualization is not contravened by experience and knowledge (specifically in reference to ethnographic findings). ‘Useful’ here means that the conceptualization provides (new) concepts and ways of thinking for empirical investigation and generative design work[31].

[31] For a philosophical elaboration of these two criteria, see Schatzki (2016).

Rational sensibility and usefulness have thus been the driving criteria behind the assembling work I have carried out. The fulfillment of these two criteria is difficult, if not impossible, to measure. The evidence must be found in the work itself. This dissertation provides demonstration that the assembled conceptualization is both rationally sensible and useful, particularly for design in transitions. Demonstration of rational sensibility was provided in the arguments for this conceptualization, in particular in chapter 2, while usefulness was demonstrated in the further chapters in which the conceptualization was put to work in relation to other fields and problems.

7.2.1. *What it means to conceptualize changes in everyday practices as improvisations*

In this dissertation, changes in everyday practices with technologies in transitions are conceptualized as **everyday improvisations.** To reflect on what this means, I briefly recap the objects, processes and relations which make up this conceptualization. In this dissertation, I have emphasized **everyday practices** as the 'objects' constituting much of daily life. They are routine, mundane activities such as bathing, cooking, doing laundry, and cleaning. Practices are socially shared, recognizable and performed by many people in a society (§1.6.1.). Following the concept of **co-performance** (§2.3.), I conceptualize everyday practices as performed, not only by humans, but also by **technologies**, which also contribute to both stability and change in practices.

Everyday practices carried out by different performers are related to each other. They are performed according to what the performers consider **appropriate practice** (§2.3.2). Human performers act according to what they consider 'normal' (in line with perceived societal norms) and fitting with the situation at hand. This aspect highlights how everyday life, even in the private realm of the home, is always influenced by societal norms. This idea is relatively novel to design, where, in human-centered design, everyday practices are considered static and often primarily functional. Next to humans, technologies also take part in everyday life. These artificial performers participate in everyday practices according to the ideas of appropriate practice held by designers and technology developers, established in the design phase. With this part of the conceptualization, I have aimed to highlight how the design phase is not a neutral space of problem-solving for users, but always assumes something about those users. It raises the question towards designers what they consider appropriate everyday practice and to what extent that idea of appropriateness is shared with users.

As part of societal **transitions** towards sustainability, specific technologies are developed and distributed with the aim of reducing energy consumption or dependance on fossil fuels in everyday life (§3.3.). Often, these technologies will include a certain level of automation (for example, indoor climate technologies switching from heating to cooling based on measured indoor and outdoor temperatures). Following the idea of co-performance, parts of practices and judgments about what is appropriate practice are thus delegated to technology automation and, by extension, to the designers that set up this automation. This aspect of automation further demands attention to exactly which practices and judgments are delegated, and whether the technologies are best placed to perform them. In this research, I have highlighted how delegation to technologies runs many risks. Chief among them is the risk of contributing to users' lack of awareness of actual energy use, as they are not involved in judging whether energy consumption is actually necessary. This lack of awareness in turn potentially contributes to a disengagement of end-users from transition goals.

Ideas of what is appropriate practice might differ between end-users and technology designers. These ideas can **conflict** with each other (§2.3.3.). Specifically in transitions, technologies and end-users are motivated by different concerns. Ideas of appropriate practice in technology development, design and policy are mostly shaped by societal goals such as sustainability, reduced energy consumption or prevention of net congestion. On the other hand, and in potential conflict, human performers of practices (end-users) have their own, situated, everyday idea of what is appropriate practice. These end-user ideas emerge from everyday concerns and societal norms, but often not from longer-term societal concerns. This is not to criticize end-users as irresponsible citizens, or just not interested in societal concerns. Rather, I have tried to make the point that our everyday practices have an internal logic; they make sense to us in that moment. These situated logics often misalign with the long arc of transition dynamics, thus creating conflicts.

In concrete situations in everyday life, differing ideas of appropriate practice between technologies and humans might result in different ideas of how to go ahead. In these cases, the underlying conflicts come to the foreground in everyday life. Concretely, a technology might act in a way that humans do not find appropriate or fitting with the situation at hand. This results in **crises of routines** (§2.6.1)**.** Crises of routines are situations in everyday life when people do not know how to go on. While the word 'crisis' might suggest a moment of great discomfort, these should rather be seen as moments where what people or technologies do is temporarily interrupted. We need a moment to stop, reflect, and think about what we (humans and technologies in co-performance) are actually doing. In understanding crises of routines in this way, emphasizing their capacity to change practices, I have attempted to indicate the potential productivity of these crises. They create moments of potential for reflection and change.

In fact, these situations of crises in routines are a potential site of **practice reconfigurations** (§3.4.). These are the processes through which everyday routines change. Something needs to change about how technologies or humans perform their part of everyday practice so that they correspond better to ideas of appropriateness. I have distinguished reconfigurations as reconfigurations of (human) knowledge, materials, or routines. Such a practice reconfiguration resolves the conflicts and (re-)aligns human and technology ideas of appropriate practice.

Sometimes, such a reconfiguration will result in a new, persistent connection between humans and technologies; an **enacted interface** (§2.3.3.). This means that the performances of humans and technologies align, connect and occur together. Being enacted in everyday practice, such an interface is not something that designers can design (entirely) beforehand. This suggests a certain humility on the side of designers and technology developers, acknowledging that ultimately, technology performances (in both senses: energy efficiency performance and their co-performing role in everyday life) are not entirely within control of the designer, but emerge from the messiness of everyday life.

Practice reconfigurations and enacted interfaces are **improvised** (§4.3.) by humans together with technologies in everyday life. They are creative, situated responses to challenges presented by everyday crises of routines. In the context of transitions, I have highlighted how these **everyday improvisations** (§4.3.) have the potential to address sustainability challenges. Each of these improvisational practice reconfigurations is a resolution of an underlying conflict (often between individual and societal concerns). In this way, they enable the technologies to be taken up in everyday practices. As everyday practices are socially shared by many people across societies, many more people might benefit from these improvisations to make the technologies fit their everyday practices. This is why I describe them as innovations-in-waiting.

The relevance of these improvisations extends beyond the household. Other actors in societal transitions, such as stakeholders in technology development (the supply side), governmental actors such as municipalities, or middle-actors might also **respond** (§4.3.) to these improvisations. Responses by these external actors might support or guide improvisations. I have introduced this notion of response with the goal of drawing attention to the practices and improvisations that are already going on. I have proposed that design, policy and technology development does not, and should not start with a blank slate, but should take ongoing improvisations seriously, as something to which they can respond. They can make end-user improvisations the point of departure for intervention.

In addition to drawing attention to the notions introduced in this conceptualization, **everyday improvisations** have actionable implications for design practices in relation to technologies in transitions. It suggests several **sites of intervention** for design, some of which are discussed in this dissertation (and summarized in §7.6.). These sites of intervention include, for example, socio-technical innovations that bridge situations of both design and use in feedback loops, or productive dialogues between technology users and technologies and designers. Other interventions could offer opportunities for experimentation, support and guiding of improvisations.

While not always spelled out, there is an implicit direction within this conceptualization. Societal transitions are journeys from one state of society to another. As such, this conceptualization, and the sites of intervention implied by it, are also directed towards this more desirable (more sustainable) state of society. Concretely: responses to everyday improvisations, the socio-technical innovations and the dialogue between technology users and designers which I have suggested, have a direction. That direction is towards contributing to the goals of transitions and thus address societal concerns. Making this direction explicit is relevant especially in contrast to human-centered design, which presents itself as agnostic towards societal goals.

7.2.2. *A more-than-human design conceptualization*

In this section, I contrast conventional conceptualizations of everyday practices in human-centered design, with the developed conceptualization of everyday practices with technologies in transitions. This section builds on the discussion presented in chapter 2. The aim of this reflection here is to substantiate what the new conceptualization of changes in practices as 'everyday improvisations' has to offer with respect to existing dominant conceptualizations of everyday practices, and what gives it a more-than-human orientation.

Concerns: From human needs to more-than-individual societal concerns

Human-centered design is a perspective that helps designers address individual user needs, and that accommodates those needs, capabilities and ways of behaving through design. This means that designers need to consider physiological, emotional or functional *user needs*. The conceptualization developed in this dissertation, on the other hand, aims to address *societal concerns* that are embedded within these technologies and the ways they are diffused in society and taken up in practices. Of course, technologies have always shaped everyday life and societies, and they always had their politics. But in this conceptualization I have aimed to be more deliberate about the 'causal impact on activities and practices' that technologies have (Schatzki, 2002, p. 197).

Technologies in transitions are developed to contribute to sustainability, which is (also) a more-than-individual-human concern. Such a more-than-individual agenda shapes what technologies do in everyday life and how they do it. Of course, this dissertation and much research on sustainable technologies shows: user needs are relevant in design decisions within transitions. It is clearly essential to the design of heat pumps to consider how they deliver a user need such as thermal comfort. However, in practical design and technology development, these user needs and wishes (such as comfort, autonomy and cognitive understanding) might end up in a trade-off with societal concerns. In the developed conceptualization, this trade-off receives proper attention, as the next section will show.

Decision-making: From positivist scientific knowledge to politics

Societal concerns and individual human needs or wishes can be in conflict (the mentioned trade-off), or in competition in concrete design decisions. Acknowledging this, this dissertation highlights how design and technology development within societal transitions has political dimensions. From this political perspective, it is possible to consider a negotiation or deliberation about those competing interests (societal and individual human). Where and how this negotiation or deliberation takes place is a question that needs to be addressed in design and technology development processes. Currently, it is within the improvisation in everyday practices with technologies that end-users negotiate their individual needs with societal concerns such as low carbon footprints. However, it might be more desirable, from a democratic standpoint, to negotiate these concerns in a more deliberative way within an (expanded) design process.

It is beyond my scope in this dissertation to suggest a specific place or form in which this political deliberation should take place (other than the sociotechnical interventions suggested in chapter 4). But whatever the shape, the question remains whether actors working on technology uptake in transition (whether they be designers, technology developers or policy makers) are ready to engage in a deliberative negotiation required to make these decisions. The responses captured in the interviews with these actors in chapter 4 were predominantly reluctant towards engaging with politics. This is understandable: a negotiation of individual human needs and societal concerns can be uncomfortable for designers. Whereas the narrative of human needs is often presented as universal, apolitical, and grounded in positivist scientific knowledge, societal concerns are of a different quality. They are not universal but range from the global to the local. They are always contested and value laden.

Relations: From use to co-performance

In a human-centered design approach, the relation between humans and technologies is typically understood as one of use. The relation is one-directional: humans use technologies. The relation is also typically conceptualized in terms of moment-to-moment interactions (Löwgren, 2013). In contrast, in the conceptualization developed in this dissertation, technologies perform their own part in a shared composite called a co-performance (Kuijer & Giaccardi, 2018). They perform everyday life together with humans. This moves technologies from being instruments for humans, often residing in the background of attention, extending human capabilities, to a new position. They become actors in the foreground, with their own performance, agency and politics. Instead of one-to-one interactions, the units of analysis and design are changes to practices, performed and repeated over longer periods of time and by many people and technologies in societies.

Change: From smooth interactions to improvisations

Human-centered design (HCD) conceptualizes friction in interactions as something to be avoided. Whether the result of human error or the result of bad design, friction is a sign for HCD that human ways of behaving are not adequately accommodated with a designed solution. In contrast, in the conceptualization developed here, friction (crises of routines), and the absence of accommodation to existing ways of behaving ('practices'), are seen as potentially productive events. It is through friction that technologies (and concerns that transcend everyday individual human life) are integrated in everyday life and aligned with individual human concerns. Friction results in improvisations, and through such improvisations, humans and technologies figure out a way to go on (Hallam & Ingold, 2021; Pink & and Leder Mackley, 2016). The underlying message of this dissertation has been for designers to embrace friction as a potential catalyst for change.

Connections: From points of control to enacted interfaces

A conventional conception of interactions between humans and technology expects people to control technologies through a central *control point*, the (graphical user-) interface. Instead, in the conceptualization developed here, connections emerge between humans and technologies as they perform everyday life together. They get 'used to each other' over time, performing routines (such as heating and cooling a room) together, and in response to each other. This leads to new relations: *enacted interfaces*. This enacted relation is a new interface; a new 'solution to the problem of matching people to things' (Pickering, 2000). These interfaces are not designed in the design phase by technology experts but enacted in relations in everyday life. Enacted interfaces are not so much about control of technology by humans, but more about the entanglements of practices performed by humans and technologies (Frauenberger, 2019). On the one hand, this might lead to frustrations for designers as everyday practices are unpredictable and the enacted interface will only be enacted (or 'start to exist') after the design phase. An enacted interface can thus not be designed in the way graphical user interfaces were designed. On the other hand, I have also tried to show that there is still considerable influence for designers over this enactment of interfaces. They can contribute by *cultivating* these enacted interfaces, but this requires being involved beyond the design phase.

Design in transitions: From design for everyday practices to everyday practices as design

A human-centered conceptualization sees everyday practices as static. Technologies are designed by professional designers and technology developers to be taken up in these practices. This design happens in a design phase preceding a use phase. The conceptualization developed in this dissertation positions design in a different way. Along with others, I see design also happening in the use phase, where technologies are locally re-invented (Jalas et al., 2017). The precise relation between technologies and end-users cannot be entirely predicted or decided in the technology development phase, but emerges in-use. This means that the change that transitions entail happens not just through technology development before use, but in everyday practices as well, and that that change is creative, experimental and improvisational. In other words, technologies are not designed for everyday practices, but design is one mode of change in everyday practices in transitions where critical sense, creativity, and practical sense are combined in the ways that doing and thinking change (Manzini, 2015).

7.2.3. *The theater as an alternative analogy*

The purpose of the developed conceptualization is to contribute to transitions, and thus to be actionable for designers, technology developers and other actors in transitions. Over the course of this research, it became clear that communicating about improvisation in everyday practices is not straightforward. Generally, technical installations such as heat pumps are viewed as ideally performing predictably and reliably, without room for improvisation. However, as my research has shown, improvisation does happen, despite these ideals. Technology developers recognize this, but tend to see it as a shortcoming that can be overcome in the next design iteration. To indicate that a different view is possible, I explored and developed an analogy, which I introduced to heat pump value chain actors. This is the analogy of the theater play, presented in chapter 4.

In this analogy, the *theater play* represents a societal transition. This play consists of many scenes. Each household in the transition performs a *scene*. The scene has multiple characters. Humans and technologies in households both have a role. Technologies perform one part of a practice (e.g., heating), and humans another part (e.g., setting the thermostat, or opening and closing windows at the right time). The scene, performed by the household, can be *directed* by external entities such as technology developers, policy makers, or others (stage directors). Human performers of the scene can be given *stage cues*, such as manuals to instruct their performance with technologies. Technological performers can be directed by programming (or automating) their performance (e.g., heat pump automation responding to outdoor temperature sensors).

But people and technologies perform their roles in different ways. Technologies follow the *scripts* set in their automations (Akrich, 1992). Human performers, on the other hand, do not have to follow a precise script, but can *improvise* on the spot and achieve their goals in multiple ways (e.g., choose between snuggling up in a blanket or changing thermostat settings). These improvisations can be encouraged, supported, discouraged or given direction by the stage directors. This has the potential to result in a better scene, performed by humans and technologies (e.g., lower energy consumption of a household). Ultimately, better scenes, including improvisations, might contribute to a better theater play (the societal transition).

This analogy proved to be useful in communicating the developed conceptualization. It highlights certain aspects of design, use and technology, and puts them in new relations with each other. It also provides an alternative for other metaphors and analogies which are commonly used in engineering discourse. For example, human inhabitants of buildings are commonly considered as sources of data, or 'sensors' of environmental data (Mahdavi & Taheri, 2017). I have attempted to show how other analogies are possible, and that they might have generative value as well. I designed the analogy with the aim of inviting the intended audience (value chain actors, often with engineering backgrounds) to see themselves as actors within the theater play. As such, there was a two-fold effect that I intended to achieve. Not only did I invite the audience to see the world and their work in a new way, but also to see themselves in a new way.

7.3. Demonstrating the value of the conceptualization by applying it to heat pump uptake in the Netherlands

This research set out to develop a conceptualization of everyday practices that should be useful for design, particularly within transitions. This development did not happen in a vacuum, but in engagement with a specific case study: the transition from conventional gas-based boiler systems to heat pumps in the Netherlands. What does this conceptualization imply for this specific case? That was the focus of **research question 1: How can this conceptualization be applied**

to everyday practices with heat pumps in the heat pump transition in the Netherlands?

Starting with the context of everyday improvisations, the **societal transition** in this case is a heating transition. The goal of this transition is to reduce carbon emissions by changing the way that domestic heat and other indoor climate related services are produced. Achieving this requires an integrated approach of (extensive) renovations and replacement of heating technologies. Heat pumps, together with the necessary indoor climate control (such as mechanical ventilation systems) are common **technologies** replacing currently prevalent gas boiler systems.

Everyday practices with these technologies are manifold. They include directly related practices of heating and cooling indoor spaces (setting the thermostat, for example), and the consumption of hot water (for taking a shower). This can be further unpacked and extended with indirectly related practices. The temperature of indoor spaces is also determined by open or closed windows and doors, by the use of solar shades, and by other sources of heat like cooking. Experienced thermal comfort is moreover dependent on a multiplicity of practices, like choice of clothes or where someone is sitting. Hot water is consumed not only by taking a shower, but also while cleaning or doing dishes. Other indirect practices related to living in low-energy housing with heat pumps are the cleaning of ventilation filters and the management of noise from the heat pump and ventilation systems.

Following the concept of **co-performance**, I understand at least some of these everyday practices as performed by not only the residents of heat pump equipped homes, but also by the heat pumps and related technologies themselves. For example, heat pumps perform their part in keeping a stable temperature by turning on and off, and by changing settings according to automations (the heating curve) in response to measured weather conditions and occupant presence. In addition, mechanical ventilation is automated based on measured CO_2 levels, and solar shades respond to weather conditions.

When it comes to specific everyday practices with heat pumps in the Netherlands, what is considered **appropriate practice** is diverse and contested. The image that emerges from my analysis in chapter 3 indicates a strong historic component. For residents, appropriate practice seems in part determined by historically ingrained practices related to the gas-based boiler systems that heat pumps replace. This includes turning down thermostats when not at home, expectations of the availability of large amounts of domestic hot water, but also gendered expectations about who manages energy consumption and how. Furthermore, residents consider appropriate practice what makes sense to them in the detailed, situated circumstances of everyday life. This includes catering to the needs and preferences of pets, and out-of-the-ordinary use of spaces (e.g., heating the attic since it is used as an office).

For technology designers of heat pumps in the Dutch context, appropriate practice includes ideas about what is a 'reasonable', cost- and energy-efficient thermostat setting, and what is 'normal' consumption of domestic hot water in a day. These ideas are to some degree implicit and rarely verbalized. On the other hand, ideas of appropriate practice are also in part encoded in building regulations and other documents. Many heat pump and associated technology configurations can, or are programmed to heat to a maximum 24°C indoor temperature. Domestic hot water production is limited to a certain amount of hot water per day, based on average household sizes. Ideas of appropriate practice also include ideas about the access that residents get to interfaces that would allow them to reprogram technical performances.

The investigations reported in this dissertation revealed that residents in this transition are not exclusively interested in their own everyday, individual human concerns. They also displayed an interest in societal concerns of continued sustainability. However, residents presented their own interpretation of what would be sustainable everyday practices, which sometimes diverged from the ideas of appropriate practice employed in the technology development phase. Examples of these are residents who kept their heat pumps turned off, or thermostat settings very low, even in winter, and residents who managed to reprogram heat pump performances to save more energy than possible in the original configuration.

Conflicts within everyday practices with heat pumps in the Netherlands, include conflicts between humans and technology about desired temperature, about when to open windows, or about the amount of domestic hot water needed, but also about when a heat pump or associated technology should be 'allowed' to produce sound. In the case studied in this research, these conflicts sometimes led to **crises of routines**. These crises included instances where people could not sleep due to the sound of a heating device, where they encountered a cold shower when domestic hot water ran out, and annoyances when residents and energy system interfaces disagreed about what is fresh air.

When these crises of routines occurred, residents engaged in **practice reconfigurations**. These are reported in chapter 3 and include reconfigurations of *knowledge*: residents learn how to heat more slowly with heat pumps, for example. Reconfigurations also applied to *routines*: residents opened balcony doors during certain periods of the day to allow pets to leave the house. *Material* reconfigurations were also observed: residents replaced automated technologies such as solar shades with their own manual solutions.

Practice reconfigurations resulted in new **enacted interfaces** between residents and technologies. These persistent connections between residents and heat pump related technologies include cases where residents perform new routines that connect and align with the performances of technologies. Examples can be found in chapter 2 and include the use of domestic hot water only on days when the system produces sufficient hot water, or moving around the house while waiting for the heat to reach certain locations. Observed enacted interfaces also include residents' careful reading of responses of pets or plants to changing indoor climate parameters.

These **improvisations** (practice reconfigurations and enacted interfaces) resolve underlying conflicts and enable heat pumps to be taken up in everyday practices. Such improvisations have the potential to contribute to sustainable transitions when they result in reduced energy consumption. They have impacts beyond households when residents share them 'horizontally' with (or copied by) other households in neighborhoods. They also have impacts 'vertically' when they change professional practices on the heat pump technology supply side, or when reconfigurations (such as improved technical configurations) are picked up and shared by social housing organizations.

Given the potential benefits of these improvisations, other actors in the heat pump transition in the Netherlands could **respond** to them. As one example of these other actors, I conducted an in-depth interview study with actors in the heat pump technology supply chain. Their responses include anticipation of improvisation, encouragements and support of improvisation, and amplification of its effects. In total, I identified ten responses to improvisation, some of which could guide and further develop improvisations. Future research could study other actors such as municipalities.

In this specific transition, and in relation to the heat pump supply chain, **actionable implications** for design in transitions include the recommendation to develop closer relationships between residents and manufacturers. These relationships could take the form of feedback loops between developers and residents, incentivizing engagement of residents, or developing platforms for sharing knowledge among residents.

This section has highlighted the value of the conceptualization in relation to a specific case of an ongoing transition. The highlighted aspects (especially improvisation in everyday practice) often remain below the surface. It is either not recognized or acknowledged by relevant actors (such as designers, technology developers and policy makers) or it is understood as a form of misuse of technologies (leading to efforts to prevent this improvisation). In applying this conceptualization in this specific case, I have attempted to provide a language and a lens that enables a more productive engagement with these improvisations.

7.4. Interdisciplinary expeditions and their challenges and contributions

As a design researcher and designer, I developed the conceptualization of everyday improvisations from my 'home' discipline of design research. I took a design research perspective, which entails that the conceptualization generatively explores the relation between everyday life and technologies. In the introduction to this dissertation (§1.5.), I introduced the problem that this conceptualization addresses as a problem not exclusive to design research, but one that spans multiple domains of knowledge. Besides design research, it also touches on the knowledge domains of societal transitions (chapter 3) and heat pump value chains (chapter 4). I address the engagement with these domains in **research question 2: How might this conceptualization contribute to questions in the domains of societal transitions and building science?**

7.4.1. *The knowledge domain of societal transitions*

The domain of societal transitions, investigated by the social science disciplines, investigates how societies change in transitions, on institutional, social and cultural, organizational, and on technological dimensions (Loorbach et al., 2017) and how this can be stimulated through (government) policy (van den Bergh et al., 2021). In this domain, one key question related to the phenomenon of everyday practices with technologies is how the micro-level of practices interacts with the macro-level of socio-technical and systems change. Technologies and innovations clearly play a role in this interaction. However, their exact relation remains contested (Keller et al., 2022). Recommendations for (technology development) practice or other prescriptive knowledge is scarce (Wiegmann et al., 2023). Here, I argue, design might have something to contribute. It might 'activate scholars' ability to critically assess existing technologies, technological components and systemic relations, and their capacity to propose alternatives' (Pineda et al., 2024).

In chapter 3, we investigated what this conceptualization (coming from design) can contribute to these questions in other domains (§3.7.), specifically by adding another layer of analysis to our ethnographic data. The chapter concluded that a design perspective highlights the relevance of the 'micro-level' of individual relations between human individuals and technologies, and the 'meso-level' of the household. It particularly draws attention to tensions between intended and actual everyday practices, and thus highlights how the success of sustainable technologies (such as heat pumps), depends on actual everyday practices. It is not enough to just replace a gas boiler system with a heat pump, as residents sometimes use more energy intensive ways of heating such as electric heaters. In being pragmatically oriented to problem solving, this design perspective also highlights barriers and opportunities to realizing these predicted energy savings. Finally, a relevant insight, possibly more novel to the field of transitions, is that 'design-like activities' also happen in technology adoption. Residents, in adopting heat pumps, come up with creative solutions to the problems they encounter, by e.g., blocking sunlight to sensors. There are similarities (in terms of creativity and innovation) between design of technologies and the uptake of those technologies in the everyday practices of the household.

For the knowledge domain of societal transitions, this results in recommendations for policy measures that support innovations to overcome the tensions between intended and actual everyday practices. Other proposals (§3.7.) include measures that contribute to the spread of innovations emerging from everyday practices.

7.4.2. *The knowledge domain of heat pump value chains*

Next to the general domain of transitions, I have identified more specialized technical knowledge domains as relevant to everyday practices with technologies in transitions. In the context of the heat pump transition at issue here, one of those domains is heat pump value chains, studied by the discipline of building science. For this domain, open questions related to everyday practices with technologies in transitions concern choosing the right technical solution, while making sure that projected energy savings are reached. The relevance of this research to these questions is that everyday practices present uncertainties. They have an impact on energy use, and they cannot be determined and predicted like the technical properties of these technologies. For example, residents set thermostats to unexpectedly high or low temperatures. These questions are particularly relevant to the supply side of technologies, such as heat pump value chains, which develop technologies and take decisions on how they are implemented.

In chapter 4, we investigated what the conceptualization of improvisational everyday practices, coming from a design perspective, can contribute to questions in the knowledge domain of building science. I did so by studying the responses of professionals in the heat pump supply side to the conceptualization. First, to communicate about it with them, I developed a sensitizing video introducing it. I then conducted semi-structured interviews with these professionals, in which I first introduced the concept to them via the video, and then interviewed them about their responses to improvisational everyday practices (§4.5.). We found that the conceptualization draws their attention to how everyday practices are relevant to energy consumption. The insights into the ways that supply side heat pump professionals engage with everyday practices complements existing knowledge in this domain on the influence of physical building properties. This conceptualization also highlighted the discrepancy between actual use practices and the ideas of supply chain heat pump professionals about how technologies are intended to be used. In the domain of building science, just as in the domain of societal transitions, a design perspective reveals similarities between technology development and use, sharing features of creativity and innovation.

For the knowledge domain of technology value chains, answering these questions results in an understanding of how closer connections between the supply and use side might contribute to uptake of technologies and a reduced net energy consumption. These connections, as socio-technical innovations, go beyond a narrow focus on technical improvements. They suggest that developing knowledge and interventions might benefit from a continuous and co-creative feedback loop between technology development and users, which relies on participation of residents and trust along the technology supply chain.

7.4.3. *Design research as a unique type of knowledge for contributing to other domains of knowledge*

Next to contributing to other knowledge domains, these expeditions beyond design research also returned insights relevant to my ‘home’ discipline of design research. On the one hand, I have, over the course of these expeditions refined the conceptualization. On the other hand, these expeditions also taught us things about design research as a discipline. Designerly ways of knowing (Cross, 1982) are different from the knowledge developed in other domains. There are several aspects that design research scholars have articulated in the past that I have found useful to reflect on what has emerged from these expeditions. In the hopes that my experiences can help future transdisciplinary design researchers, I describe some of the reflections, challenges and opportunities I encountered in carrying out this research.

Usefulness

Schatzki identifies usefulness as one criterium for 'good' conceptualizations. Useful, in social theory, means that conceptualizations are good for *"raising issues, conceptualising objects of study, and providing descriptions, explanations, and interpretations"* (2016). This can be described as 'epistemological usefulness': conceptualizations are useful for theory or knowledge. In writing for and presenting for audiences in the social sciences (transition studies), I have noticed that this epistemological usefulness is appreciated in the contributed conceptualization. However, design research can also offer another type of usefulness; a usefulness that is more pragmatic in nature. This, I think, originates in the interventionist and future-oriented nature of design research (Gunn et al., 2013, p. 13). Whereas many (social) disciplines aim to be descriptive, and for that reason take the past or the present as object of inquiry, design research does not just describe, but intervenes and generates. As such, the criteria by which the products of design research are evaluated are also oriented towards interventions and towards the future. Thus, the conceptualization developed in this research is to be evaluated (also) by the degree to which it can generate, or point to, sites of intervention. When evaluating usefulness, the sections of texts and presentations in which I discuss 'implications for design' (Dourish, 2006) demand attention. These implication sections of each chapter, are, when it comes to *usefulness*, the basis on which the evaluation of the research should take place. This, it seems, was also recognized by reviewers of the papers on which these chapters are based, as these implication sections received high degrees of attention in the peer review process.

Overcoming frictions

Transdisciplinary engagements are not straightforward. There are many aspects on which synergy between disciplines and fields can fail. In this research, I have noticed frictions between paradigms and worldviews of engineering (in which societal issues and everyday practices are considered outside of the scope) and transition scholars (with less interest in the details of technologies). A conceptualization that integrates both (everyday practices in transitions, and technology features) is not an 'easy sell' in engineering and transition disciplines. I encountered conflicts and misunderstandings about languages, conventions and goals between different fields.

The animated video developed in chapter 4, for example, was appreciated and understood (§4.6.1.) by the engineering-oriented supply side actors, but this does not mean that the presented conceptualization was effectively adopted in these organizations. In later reflections, I noticed that the metaphoric part of the video (see chapter 4 for a full description) was understood and appreciated better than the second part, in which I proposed interventions. The way I understand this two-fold reception of the video is that I was successful at speaking the language and metaphors of the field of supply side actors, but might not have communicated or appreciated well enough how their goals and the means that they have at their disposal for achieving these goals fit with design interventions. Only by spending (even) more time or becoming closely embedded within fields, it is possible to learn the way these organizations are organized and what interventions might be put forward that will be more readily accepted.

Designerly transdisciplinarity

Reflecting on transdisciplinary research, I have found a few concepts useful in discussing the process, concepts which are notably 'designerly'. In learning to speak the languages of different fields, and understanding what design research and the conceptualization under development might have to offer, I found a 'prototyping' approach most useful. For example, my first engagement with the field of transition studies was by submitting a draft two-page abstract to an academic workshop, held in Prato. Attending the workshop then allowed me to sharpen arguments and explanations, ultimately leading to a full paper (chapter 3), making a contribution to the field. Similarly, engaging with the discipline of building science did not start with contributing a full scientific paper, but with engagements with consortium partners, workshops at conferences (Powerweb (TU Delft PowerWeb Institute, 2022), SBE (van Beek, 2022)) and a presentation of a short paper at the Clima conference (van Beek & Boess, 2022). These prototypical endeavors supported learning about how other disciplines and scientific practices 'work'. They also enabled me to 'fail early' in communications with these fields, when my explanations at early workshops were understood differently than I had anticipated.

Nomadism

In the introduction to this dissertation (§1.10.2), I introduced a rather straightforward description of interdisciplinary research. This original description, based on ideas by Balsiger (2004), proposed a 'guide and supply' relation, where one 'guiding' discipline formulates a task, which can be dealt with by the second 'supplying' discipline.

However, reflecting on this research, I have noticed that such a one-dimensional relationship is not an adequate reflection of my personal experiences in doing transdisciplinary research. Such a 'guide and supply' understanding seems to indicate that a researcher from a specific (supplying) discipline contributes to another. This, however, assumes the existence of fixed boundaries of disciplines, and a researcher that 'stays within' their discipline. In my experience however, I was not just a design researcher venturing into other disciplines, but I 'became a transition studies scholar' (at least for a while).

Balsiger (2004) already questioned the stability of disciplinary boundaries and emphasized that disciplines primarily exist at an institutional level and that research practices are different. A more adequate description of my experience of transdisciplinary research then, might do away with the idea of disciplines and instead understand research as a nomadic practice (Wakkary, 2020). The idea of nomadic practices is that they are not structured around a foundational knowledge like a discipline or subdiscipline (Wakkary, 2020). Building on the ideas of situated knowledges (Haraway, 1988) and territories (Deleuze & Guattari, 1993), Wakkary highlights that a nomadic practice is a *view from somewhere* with a particular genealogy of the researcher traversing across a landscape. This, I recognize in my own interdisciplinary engagements. Design research, as reported in this dissertation, does not have a static method or object of research, but is better described as nomadic, following societal and 'wicked' problems around, forming temporary alliances with other fields on the go.

7.5. From a conceptualization of everyday practices to design methodological proposals

Conceptualizations become operational in methods. The tradition and practice of design has many methods and techniques at its disposal for designing. They include prototyping, user interviews, storyboards and other methods for understanding current, and anticipating future effects of designs and technologies[32]. These prescriptive schemes can be seen as ways to operationalize theories and conceptualizations for the purpose of design. User interviews, for example, assume that user perspectives are relevant for design practices and outcomes, and that these perspectives can be elicited and recorded. Prototyping of user interfaces, on the other hand, can be seen as an operationalization of a conceptualization of use in which some relevant user behaviors or preferences are implicit, and only come to the fore in staged interactions of people with a design. These conceptualizations do not exclude, but typically complement one another (as user interviews and prototyping are often used in the same process).

One way in which a conceptualization can be operationalized, is through (visual) representation of information and concepts[33]. This is the approach I took in addressing **research question 3: How might relevant dimensions of everyday practices with technologies in transition be operationalized for design?** Many methods and tools for design rely on visual representations of certain aspects of a situation or a design. Visual representations operationalize a certain (implicit) conceptualization by presenting, mapping and diagramming elements and their relations with marks or symbols. Service blueprints, for example, visually abstract and represent a service and the related user experience. Service blueprints operationalize a conceptualization where services consist of frontstage touchpoints and backstage support processes.

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[32] A collection of examples can be found in the Delft Design Guide (van Boeijen et al., 2020)

[33] Not to be confused with the prototype as a representation of an imagined 'real product'. Visual representation in the way that I use it here, has the purpose of creating overview and simplification of complexity (Blackwell, 2011). Representation in the sense of prototyping has the purpose of testing and confronting a design with the 'real world', which creates a strive for realism instead of abstraction (Bødker, 1998).

Over the course of this dissertation, I have introduced a conceptualization of everyday practices with technologies in transitions. This conceptualization consists out of multiple elements and dimensions (e.g., human-technology relations, improvisational use, enacted interfaces, and connections between societal transitions and everyday practices (c.f. §7.2.1.). Some of these elements and dimensions have not featured prominently (or in this way), in established design practices and in common design methods and techniques. This led us to operationalize the developed conceptualization, and develop and present two ways of representing dimensions of everyday practices which are relevant to design practices.

I have introduced two design methodological proposals that operationalize the conceptualization of everyday practices with technologies in transitions, in four interrelated dimensions (*the temporal dimension, underlying ideas of appropriate practice, design capacities,* and *boundaries to design capacities)*. These visual representations have proven to be effective in communicating the relevant dimensions and highlighting them for an audience of design researchers at international conferences (IASDR 2023 and DRS 2024, respectively). Here I reflect further on their value.

7.5.1. Highlighting for design methodology the temporal dimension and ideas of appropriate practice

One challenge in design and engineering is to imagine the temporal dimension of how people will interact with artifacts. The conceptualization of everyday improvisation presents an added challenge to this: that of grasping that practices change and take place over different time spans. It also challenges the idea that it is only humans that act, while technologies are resources or passively standing by. To address this, I make use of dramaturgical approaches and propose the method of the screenplay. The basis for this is developed in chapter 2 where we identify the temporal dimension (§2.6.2.) and ideas of appropriate practice (§2.6.1.) as relevant aspects of the conceptualization. Then, in chapter 5, we discuss how co-performances (one element of the conceptualization), might be represented in a new way using an existing visual vocabulary. We find that the screenplay (or movie script) provides a way to represent these two dimensions of everyday practices with technologies (as present in our ethnographic data). The visual layout and vocabulary of slug lines and narrative descriptions used in the screenplay, represent the *temporal dimension* of everyday practices. They enable a way to visualize, represent and communicate how everyday practices change and take place over different time spans. The second dimension of everyday practices with technologies represented in the screenplay, is that of *ideas of appropriate practice*. Through the use of parentheticals indicating the motivation, logic or know-how behind the actions of both technologies and humans, one can represent ideas of appropriate practice motivating these actions, and also describe how these ideas change. In chapter 5, we find that the screenplay is an effective vocabulary for reading everyday practices with technologies, and specifically enacted interfaces. We also propose that this screenplay might be used, not only to represent and analyze past performances of practices (from ethnographic data), but also to anticipate and envision future everyday practices in design processes.

The screenplay is not an accidental choice, just driven by a search for visual representations. Instead, it reflects a commitment towards the *performative* aspect, which I believe is often insufficiently articulated when it comes to design and what technologies do. This *performativity* (in the many senses of the word (e.g., Barad, 2003; Butler, 1988; Goffman, 1974; Schechner & Brady, 2013) and already indicated by the notion of co-performance) emphasizes that what one does is both influenced by what is considered normal, and an influence on those social norms themselves. Articulating where and how actors follow, or respond to those social norms, how those norms can be hidden, but are always present, is something that performativity and dramaturgical approaches have to offer. The novelty in my proposal for the screenplay lies in bringing technologies in as actors themselves. Differently from people participating in everyday practices, they do not have the capacities to be aware of, or immediately respond to, social norms (appropriate practice). Instead, their actions are a consequence of the way they are programmed and designed by technology developers. They thus embody the social norms and ideas of appropriate practice held by designers. The screenplay thus brings in a set of dramaturgical notions and tools that can be of help in critically reflecting on and specifying the mutual shaping of technologies and societies in transition. Examples are notions like stage (Goffman, 1974), transitions (Benford et al., 2009) and spectators (Sauter, 2004), all worth further exploring in future design research.

In the context of concrete design activities in societal transitions (such as the ongoing Dutch energy transition), the methodological proposal of the screenplay might find a place in the practices of interface-, service- or user experience designers working in, for example, heat pump companies or energy providers. As a visualizing method, it broadens existing ideas of what a user interface and the service provided by an energy company deliver. However, taking this methodological proposal up in design practice requires further validation based on ethnographic and / or sensor data gathered from the technologies and services delivered by these organizations. This could result in screenplay documents as boundary objects or design artifacts useful in making or providing arguments for design decisions to e.g., management.

7.5.2. Highlighting for design methodology that design capacities exist in various design spaces

A further challenge for designers is to imagine, anticipate and reflect on how design happens not just by designers, but by many other actors and in other phases than the formally designated design part of technology development. In chapter 2, we discuss how, in our conceptualization, design capacities are not just present in the technology development process, but become distributed among designers, users and technologies (§2.6.). We also highlighted that what designers consider appropriate practice of each of these actors determines which design decisions are implemented (§2.6.1.). In chapter 6, based on speculative design experiments, I introduce a two-dimensional mapping of design spaces as a way to represent and communicate *design capacities* in different phases of the 'biography' of a technology. With time on the one axis, and the size of design spaces on the other, this visualization presents an opportunity to make design capacities explicit. Design spaces, visualized as areas with boundaries, located in design and use situations, provide a way to represent and compare these design capacities. Where the boundaries of these spaces are placed, indicates the range of what is considered an acceptable design outcome. In the developed conceptualization, this boundary is, among other things, determined by *appropriate practice.* Thus, mapping the design spaces is proposed as a way for designers to consider, communicate and anticipate appropriate design decisions, even when design happens outside formal design or technology development situations.

Unlike the screenplay method (which can draw on ethnographically collected data), the visualization of design spaces is a method that is still largely based on my own interpretation at present. There is, to my knowledge, little data available that describes the boundaries of a design space (what is considered appropriate for each actor and what is not). Probably, discovering these boundaries can only happen within design practice itself. It requires designers to attune to their own social and cultural conditions, and to the conditions in which their designs will end up. It requires a critical reflection-in-action (in the 'Schön-ian' sense (Schön, 1992)) on one's own practice to uncover what one considers normal and appropriate, and what drives those assumptions. As I have attempted to show, arguments driving design decisions, including those that seem pragmatic, functional or efficiency-driven, are also shaped by cultural norms, effectively shaping the design space.

Here again, applying this methodological proposal in design activities in societal transitions (such as the Dutch energy transition) could happen in the practices of interface-, service- or user experience designers working in e.g., heat pump companies or energy providers. As a methodological proposal, it might serve a tool for (self-)reflection and visualization, which helps reflect on design decisions. Appropriating it in design practice requires further validation (beyond my earlier presentation of this work at the DRS conference). Such validation could take place with designers in practice working with this visualization in e.g., a workshop testing setting. This should reveal important considerations such as: are the visualizations applicable to all cases? Do designers potentially already use concepts like appropriateness or design spaces, but in different terms (as also suggested in other chapters of this dissertation (§4.5.3)?

7.6. Sites of intervention for design engaging with everyday improvisations

The conceptualization offers designers direction for where they might put their efforts when addressing transition challenges. But this requires a further operationalization, pointing to sites of intervention for design. This addresses **research question 4: What are sites of intervention for design practices in transitions that follow from this conceptualization?** To be clear, I position design not (only) as involved in technology development, but more generally as a field of practice that 'devises courses of action aimed at changing existing situations into preferred ones' (Simon, 1969). These descriptions of sites of intervention for design is an example of intermediate level knowledge (Höök & Löwgren, 2012). This intermediate level knowledge brings the higher-level conceptualization to a more concrete instantiation. The point is not to be exhaustive or generalizable, but to propose some directions.

In this way, these sites of intervention indicate areas to which designers, addressing transition goals in which technologies play a role, might direct their attention. Here, I organize these implications in three sites of intervention, reflecting different timeframes. §7.6.1. is about what design can do *before* improvisation. §7.6.2. is about responding to improvisation *as or after it happens*. §7.6.3. is about how design can facilitate a *feedback loop* of enabling and responding to improvisation.

7.6.1. *Setting the stage for improvisation*

The developed conceptualization recognizes that technologies in transitions require reconfigurations of everyday practices. These improvisational reconfigurations can be supported *before* implementation of these technologies.

Everyday practices, and the everyday concerns that feature in these practices (such as care for pets, spontaneous ideas, and changing circumstances which feature in ethnographic data), are impossible to fully predict or anticipate in the design phase (§2.6.2). Therefore, technologies should not be over-determined in the way they are used. From this perspective, the challenge for design is not one of discovering the intentions of human users and then enabling the technology to act upon these intentions. The challenge is to design a certain openness and configurability into technologies in transitions to relate and respond to everyday practices of human and other entities (§2.6.3.)[34].

Concretely, designers could design technologies (and other material elements such as control interfaces to these technologies) that are not just fit for one type of use (and one type of household) but would perform well in diverse situations (or use cases). Improvisations can be supported when technologies and interfaces can be repurposed and re-interpreted to play a role in diverse practices. Since technologies in transitions need to be locally reinvented (Jalas et al., 2017) to fit everyday practices, and that reinvention results in user innovations (§1.4.2.) my conceptualization suggests technologies that are *unfinished, correctible, modular* and *flexible* which enables practice reconfigurations and enacted interfaces. Examples could be heat pump programming that can be changed by users, or connection points for different interfaces supported through open communication standards. I am not the first to argue for this openness in technologies (e.g., Botero et al., 2010; Giaccardi & Fischer, 2008; Redström, 2006). However, this argument gains extra weight in light of societal transitions in which technologies are developed for more-than-individual-human concerns and diffused to be adopted in a wide variety of situations. Taking these technologies up in everyday practice requires alignment of

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[34] As argued in chapter 2 (§2.6.3.) I also propose an alternative to the existing stream of design research which is focused on changing user behavior. Our intent is not to design for the pre-determined human behaviors which are 'right' or sustainable. The point is to be open to reinterpretation and conflicting concerns.

everyday individual concerns and societal concerns, a process which can be supported in the design of technologies.

Beyond this openness in the material dimension of technologies and interfaces, design before technology implementation could contribute to a *staging of crises of everyday routines*. As this dissertation has demonstrated, improvisation has productive potentials and might contribute to transitions through proto-practices or innovations-in-waiting (§3.4.) some of which result in decreased net energy consumption. Design interventions (such as interfaces, or specific ways in which technology automations are programmed) could contribute by enabling or potentially even supporting friction. On the one hand, this enables learning and exploration of new technologies which is of value to end-users. On the other hand, it stages a deliberative dialogue on goals that conflict between end-users and technologies (§2.6.3.). Concrete examples are thermostats which slowly decrease set temperatures, requiring active involvement of residents to stay warm. This could provoke end-users to reflect, negotiate and explore alternatives to staying warm, or in other ways consuming energy. This aligns with existing adversarial, critical, provocative or agonistic ideas of design which facilitate reflection for democratic purposes (c.f. DiSalvo, 2012). However, instead of the public sphere, the deliberation understood from the developed conceptualization in this dissertation, happens within the practices of everyday life (c.f. Marres, 2012).

Furthermore, our conceptualization holds that everyday practices are performed by both humans and technologies. Improvisation also means that certain practices are dynamically delegated from humans to technologies and vice versa (§2.6.1.). Design that sets the stage for improvisation means that it creates room for dynamics in divisions of tasks. In other words, there should be some room for users deciding 'I'll do this myself' or systems requesting manual interventions in automated performances. This proposal again aligns with existing ideas of technology responsiveness (Giaccardi & Redström, 2020). In the context of societal transitions, this responsiveness enables the alignment of both situated needs and more-than-individual-human (i.e., societal) concerns.

7.6.2. *Responding to improvisation*

In this dissertation, I suggested that design could respond to improvisation (chapter 4). While impossible to entirely predict improvisation with technologies in transitions, designers involved in transitions could still *respond* to improvisational practice reconfigurations. This might take different shapes. Successful, beneficial, sustainability oriented, or otherwise desirable improvisations could be picked up, monitored and distributed when or after they happen.

Responding to improvisation, first, requires, *close attention* to existing places where potential cases of improvisation might be reported. This can be found in places where technology feedback is gathered, for example, on online forums. Additionally, design practices often already involve some forms of ethnographic research (Crabtree et al., 2012). Here as well, designers might be able to pick up on improvisations. Other resources might be monitoring or quantitative data collection which can offer occasions to notice improvisation. Additionally, new channels for continuous communication and feedback could be established (§4.6.2.).

These channels or platforms might not just facilitate communication between end-users and technology designers, but might also facilitate knowledge *sharing between users*. Similar to neighbors taking inspiration about improvisation from each other (as reported in chapter 3), designers could propose platforms to enable sharing and incentivizing improvisations and other forms of user and community engagement with technologies in transitions. These might be local and embodied (for example: demonstration homes (Boess, 2022)) or possibly facilitated by digital tools and social media. On these platforms, designers might contribute by surfacing, articulating, and supporting potentially successful, or innovative alternatives (Botero & Hyysalo, 2013).

Furthermore, future design practices might *propose improvisation* or experimental practice reconfigurations to end-users. Here, the attention of designers to everyday practices can connect to technology expertise (§3.7.2.). Existing work in practice-oriented design has already proposed possible methodologies that might be used for this purpose (Kuijer, 2018; Scott et al., 2012). A wide range of design tools is used in these methodologies (trigger products, low-fidelity prototypes, design of communication tools, etc.) (Giaccardi & Nicenboim, 2018; Kuijer, 2014). Appropriating these methodologies from their original conception will require additional attention to specific technologies (in this case heat pumps), and to the dynamics of transitions.

Responses to improvisation, as sites of intervention, have their own *time and place*: it might, e.g., be most beneficial to encourage improvisation when residents have newly moved in. Similarly, it might not be necessary (or feasible) to involve all end-users of technologies. Instead, a start can be made with willing, enthusiastic or influential users in specific neighborhoods or other environments.

7.6.3. Facilitating responsiveness to improvisation

Beyond facilitation of improvisation itself, and beyond responding to improvisation, designers might also design feedback loops which facilitate these responses. Responding (understood similar to response-ability or the ability to respond (Barad, 2007, p. 392)) is a relational quality. It is not (just) something that designers do, but a quality of the relation between designers, users and technologies.

There is always a recursive relation between design and use (Kuijer & Giaccardi, 2018). Users have their own ideas of appropriate practice, which ultimately influences how designers design. This means that in the long loop of design and use, end-users always play a role. However, from the perspective implied by the conceptualization developed in this dissertation, this feedback loop can become shorter and tighter. A short feedback loop means that situations of use and design are closer related, and possibly even co-evolve with each other, without resulting in a stable outcome in the form of a technology and its use. It is not feasible within the scope of this dissertation to sketch out a complete framework for such a feedback loop. However, some directions for design practices can be extracted from the discussion that might become ingredients in a framework. These are not necessarily novel, but are here placed in relation to everyday practices with technologies in transitions.

First, within such a framework, designers would *collaborate with end-users* and regard them as co-designers and co-innovators. Collaboration with end-users goes further than the sharing of information or passive monitoring. It requires taking seriously the innovations that users make (Von Hippel, 2006). Furthermore, following our conceptualization, improvisation happens in everyday practices, in situations of use (§2.1.). Therefore, this kind of collaboration is not just a matter of conventional forms of participatory or co-design (Botero & Hyysalo, 2013), which happen primarily in design-time, but it extends beyond (or rather blurs) the delivery moment of a technology (§4.6.2.).

Such a feedback loop will also require *organizational structures that integrate technologies and humans (designers and users)* (§4.6.2.). These structures can be organized around specific technologies (e.g., heat pumps), around specific goals (e.g., time-shifting energy consumption), or around specific locations (e.g., neighborhoods). The main strategy has to be one of making connections that facilitate access between elements (human and technological) that need to collaborate or co-evolve. These structures can build upon existing structures of living labs and learning communities, ultimately forming evolving communities of (learning) technologies and innovating humans.

Facilitating responsiveness, especially in societal transitions, suggests a *flexibility in direction*. Societal transitions are about concerns that transcend individual human citizens. Addressing those concerns is not achieved with a single-bullet technology or with users adopting precisely the right everyday practice. In complex and dynamic societies, responsiveness transcends choices of technologies, or judgments about the right (most sustainable) everyday practices. Instead, technologies and existing everyday practices are starting points in evolving relations of users, designers and technologies. Only in this way can transition goals be achieved. However, these transition goals themselves are also in continuous flux. The Dutch heating transition, for example, springs from a legacy of technologies, practices and societal structures that, in light of current societal challenges (energy consumption) need to change. But those conditions will be different in future transitions, thus requiring new transition goals. A framework for design, if it does not again want to become a part of the problem (§1.1.), must have a flexible direction, while being responsible and accountable in the face of societal transitions.

Finally, designing towards a feedback loop that facilitates responsiveness requires *trust* among different actors. When direction and goals of transitions are flexible, staying on the same path is not straightforward, but requires active work. Here, I understand trust as the other side of responsiveness. There is only a possibility of sharing the same transition (a transition as design (§7.2.3.)) when designers and technology users together take responsibility for their reconfigurations of (shared) design- and everyday practices.

7.7. Further implications

Beyond the implications for design in transitions (§7.6.), this section draws out some further implications and recommendations for different audiences, gathered throughout the research presented in this dissertation. I first focus on transition policy and select the most important implications mentioned in chapter 3 and then develop implications for technology development and value chains, primarily reiterating recommendations from chapter 4.

7.7.1. Transition policy: Shifting focus from technology roll-out to supporting practice reconfigurations

Policies in sustainable transitions with technologies are increasingly targeting households (Raven et al., 2021). This move towards households aligns with the findings of this research and the developed conceptualization. From this research follows an appreciation of households as not just receivers of technologies, but as creative actors in transitions. Concretely, for policy in transitions, this means a focus beyond technology roll-out where policy can support practice reconfigurations in households when technologies are implemented. To give a few examples following from our identification of three types of practice reconfigurations (knowledge, material and routine) (§3.7.1.): reconfigurations of knowledge could be supported with learning materials, material reconfigurations could be supported with a more holistic approach towards technology roll-out (e.g., including sound insulation, and not just heat pumps in subsidies), and routine reconfigurations could be supported with dynamic energy tariffs.

On a more general level of policy, this research implies recommendations that promote bottom-up innovation emerging from (creative and front-runner) households. This can be encouraged through existing transition policy approaches such as niche-development, experimentation and the amplification of innovations. Concrete institutional structures can integrate these approaches in, for example, living labs.

In the long term, policy measures should account for the dynamics of transitions. Social practices, technology uptake, and the goals of societal transitions are all shifting targets. Likewise, supporting transitions with technologies in late-follower countries might have to be different from the support required in early-adopter countries. This understanding of transitions as dynamic also encourages an experimental approach to policy which implements temporary measures (such as subsidies or regulations), evaluates these measures and can shift targets when transitions develop and evolve.

7.7.2. New relations among value chain actors and technology development

This research and the developed conceptualization have implications that suggest changes to technology development and value chain actors. In part, these implications concern the specifics of technologies. Understanding change in everyday practices with technologies as improvisation suggest technologies that are open to diverse kinds of use. While, from a technology development perspective, there might be one intended use (the most energy efficient or frugal use pattern), this research has suggested that technologies could be developed to fit with diverse use patterns. This would support technology uptake in diverse households and has the potential to result in innovative practice reconfigurations.

Beyond the specifics of technologies, this research has suggested that value chain actors develop new relations among themselves and with households as end-users of technologies. Concretely, this can entail participation in online forums where end-users share their innovations, site visits to technologies in use, and more. These contact points with end-users should not only pay attention to practices of individual end-users, but also identify (and potentially amplify) the impact beyond individual end-user (household) practices, on neighbors and the further social environment. Additionally, new relations among value chain actors (such as manufacturers and installers) should focus on learning from end-users, and dynamically updating communication (such as instruction manuals or information events) according to insights developed from within the household. Within the borders of organizations, this research has suggested the development of new organizational structures like innovation divisions, which enable organizational learning over the course of multiple projects, preventing acquired knowledge from being lost when a project finishes.

7.7.3. The critical role of households

The final set of implications is directed towards households, citizens, and technology end-users, emphasizing the critical role they play in shaping sustainable transitions. This research underscores the value of creativity, innovation, and experimentation within everyday practices, particularly in how households interact with and adapt to new technologies. However, it is not enough for these innovative efforts to remain isolated within individual households. The broader potential lies in sharing these insights and practices beyond the household, contributing to a collective movement toward sustainable transitions.

Households are not merely passive recipients of technological change but active participants in shaping how these technologies are integrated into daily life. Recognizing this agency is essential in resisting the unchecked automation of daily practices that might otherwise limit the potential for creative engagement. By participating in transition politics—both within and beyond conventional political arenas—households can advocate for and influence the direction of technological and social change.

Finally, the research calls on households and citizens to embrace creativity and experimentation as central to their role in sustainable transitions. This involves engaging with the broader community, sharing experiences, and influencing the social and technological landscape beyond the confines of the household. It is ultimately up to all of us active citizens, to shape the future of sustainable transitions through our everyday practices, ensuring that these transitions are inclusive, dynamic, and reflective of the diverse needs and aspirations of societies.

7.8. Limitations and future research

The conceptualization developed in this dissertation can be extended in future work. First, it is a conceptualization of one phenomenon (everyday practices) among many other phenomena. Other phenomena in the world with potential relevance to transitions (e.g., oil prices or energy production systems) are not included. Second, this dissertation has only captured and made explicit a few concepts that form a part of this conceptualization. Future work could follow the commitments implied by this conceptualization and extend it further. For example, I have primarily focused on changes to everyday practices that can be anticipated (replacements of technologies, for example). I did not research how 'freak events' (like sudden major technology breakdowns) would fit within this conceptualization. Future work could extend the conceptualization and make explicit how such a freak event could be understood (or even designed for and with).

While this dissertation contributes valuable insights by presenting a conceptualization that has been shown to apply to the heat pump transition in the Netherlands, it is important to acknowledge several limitations that may affect the transferability of these findings to other locations, transitions, and technologies.

7.8.1. Beyond this case

First, the case study focused on the Dutch heating transition, a specific societal transition that heavily relies on technology. Heating and housing are necessities in colder climates, typically considered indispensable for daily life, unlike many other technologies. This aspect of the heat pump transition might mean that the findings are less applicable to transitions involving more 'optional' technologies (e.g., transitions from car to shared bike use), where adoption and integration dynamics could differ significantly. In addition, technologies in transition are not just new introductions, or less resource intensive replacements. Transitions can (and should) also move towards much more radical change in technology use. The bike, replacing (a portion of) car use, might be a more important technology in transitions towards sustainable transport than the electric car (Brömmelstroet et al., 2022). The findings from this case study of heat pumps, can be extended to the broad category of 'consumer technology' (of which heat pumps are a part) with which everyday practices are situated within the home. However, more work might be required to apply the conceptualization to include other types of technologies: infrastructural, industrial or municipal technologies, such as electric public transport. Future research should therefore investigate the applicability of the developed conceptualization to other transitions, in the past, the present and in the future.

The research was conducted over a four-year period, and each study only took a snapshot of ongoing changes in households and in the supply side of heat pumps. Given this relatively short timeframe, in my PhD research I was unable to capture the long-term dynamics of transitions, which might evolve differently over decades or generations. Instead, the focus was on relatively fast-shifting practices, and it remains uncertain whether these short-term dynamics are more or less influential than longer-term trends. The lack of a historical or longitudinal analysis limits my understanding of how practices might stabilize or change over a more extended period.

The design methodological proposals operationalizing the developed conceptualization and employed in this research (chapters 5 and 6) have been shown to be applicable to the gathered data and have produced new insights into ethnographic findings. These methods have not been tested beyond the specific case of the Dutch heating transition. While they demonstrate utility in this context, their effectiveness for anticipation, broader application, or communication of design concepts remains unproven. Future research could explore these methods in different settings and over longer periods to assess their generalizability, transferability and robustness.

7.8.2. Research methodological limitations

Future research should also deepen an understanding of the role of end-users within their households. While the sensitizing video presented in chapter 4 introduced some specific examples, there is still a lack of comprehensive knowledge within technology development practices about situated actions within households and the various factors that influence and disrupt everyday practices, especially when new technologies are introduced. These dynamics are crucial for understanding how sustainable transitions can be effectively supported and scaled. Such an understanding can grow out of more engagement between the fields of sustainability transitions and research focusing on technology appropriation (e.g., Dourish, 2004) and domestication (e.g., Berker, 2011).

Moreover, the ethnographic approach taken in this research (chapters 2 and 3), including the number of visited households, also presents some constraints. The study involved a limited number of households, with a significant proportion being tenants rather than homeowners. In these cases, technological decisions were often made by professionals rather than the residents themselves, which might have skewed the findings toward a perspective where household agency in decision-making is reduced. Additionally, the focus on crises-in-routines may have led to an emphasis on more extreme or atypical behaviors, potentially limiting perception of how everyday life unfolds more smoothly and regularly.

The semi-structured interviews with sensitizing videos, which served as a key method for data collection, also have their limitations. The analysis in chapter 4 was based on interviews, and thereby could only analyze reported professional practices, without direct observation, introducing the potential for memory bias. Some practices were mentioned only as ideas or one-time occurrences rather than consistent, structural behaviors. This makes it difficult to assess the applicability of these responses across broader contexts. Future work could undertake a comprehensive evaluation of the practices encountered. The study focused primarily on manufacturers, and thereby omitted the early phases of product development, the moment of installation of heat pumps, and the construction period, which could have provided a more complete picture of the process.

7.8.3. A design research approach towards a framework

A design research approach offers a valuable framework for addressing these challenges. By engaging in a continuous and co-creative feedback loop, design research has the potential to help develop both the necessary knowledge and practical interventions. This approach allows for iterative testing and refinement of socio-technical innovations, ensuring that they are responsive to the realities of household practices and can be effectively integrated into everyday life. Thus, future research should prioritize this integrative and adaptive method to enhance both the theoretical and practical aspects of sustainable transitions.

This dissertation presents first steps towards an operationalization of the insights, ideas, and conceptualization presented in this research for design in transitions. For example, the developed conceptualization has been shown to be useful in informing visual representations that operationalize the conceptualization (§7.5.) and in directing to sites of intervention (§7.6.). As such, the efforts presented here have been primarily directed towards analyzing current everyday practices and defining objectives for design. However, it is also known that design (and other practical disciplines and practitioners) needs concrete programs, processes, and action plans to work with. Once the conceptualization has been tested and found to apply more broadly, future research could develop a more general framework, both for design and beyond. Such a framework requires a close collaboration of academia and design practice, and might ultimately find a place within (design) education.

7.9. Final reflections on design with anthropology

The epigraph opening this dissertation are the words of anthropologist Tim Ingold, who provocatively questions whether design for improvisation can ever be anything but a contradiction in terms (2016). His point is that design (always) sets rules for users. Designed objects are meant to be used in a particular way, determined by designers. This turns users into consumers, leaving little room for improvisation. Yet, in this dissertation I have attempted to not shy away from this apparent contradiction but to embrace it as a challenge. I have conceptualized design as an activity of not only designers, but of users in improvisational co-performances with technologies, outside the traditional design phase. I have also argued that designers should respond to and engage productively with these improvisations. This links design and improvisation, not as design *for* improvisation, but in a different way. I have argued that it is possible to design *with* improvisation, if designers stay engaged, pay close attention, and respond to what happens when technologies and users become ‘used to each other’.

Doing so has turned this research into a dissertation that does not entirely follow the archetypes of PhD-theses in design research (c.f. Feast, 2023). Instead, it aligns more closely with the emerging field of design anthropology (Pink et al., 2022; R. C. Smith et al., 2016). Design anthropology is a 'distinct way of knowing, one which incorporates both analysis and intervention in the process of constructing knowledge' (R. C. Smith & Otto, 2016). While design intervention was limited in the ethnographic work, the overall arc of the dissertation can be characterized as design anthropological. In the ethnographic work, I brought in a designer perspective. This designer 'apparatus' is sensitive to what might be called the 'dialectics of problems and solutions': improvisation, experimentation and innovation. In consequence, the ethnographic conversations and observations were drawn towards understanding the solutions that participants came up with to deal with the various challenges they encountered in living with technologies. In my site visits I participated in discovering solutions (improvisations) that people develop to address these challenges.

This ethnographic participation was not just targeted at developing knowledge, but had the aim of identifying and scaffolding potential change (R. C. Smith & Otto, 2016). This potential change was then further supported when my ethnographically collected improvisations were shared with other stakeholders later in the research project. This aligns with design anthropological commitments to learn together with stakeholders in future-oriented spaces (Pink et al., 2022, p. 183).

According to Kjærsgaard and Otto (2016), doing design anthropology involves navigating the delicate balance between being a provocateur and an analyst, with intervention at its core. Anthropology has a tradition of cultural critique, often disorienting the reader and altering their perception through ethnographic descriptions of 'the other'. Similarly, the work reported in this dissertation was intentionally designed to make an impact (on research participants and otherwise, for example in workshops and a sensitizing video). The work, especially in the second part, involved disruptive and interventional practices, complicating dominant visions of the present and the future (Pink et al., 2022, p. 183). The goal has not been to create a sense of stability but to provoke reflection and challenge assumptions.

Out of the many possible configurations of design and anthropology (Singh et al., 2021), I believe this dissertation might be an instance of design *with* anthropology. Anthropology was not in service of design, nor vice versa, but the creative, experimental, future-oriented aspects of design are found in the ethnographic work itself (the *improvisations*) and in how I and other stakeholders engaged with them.

7.10. Conclusions

In conclusion, the challenges faced by society today demand ways of thinking and designing that go beyond individual user problems. User-centered design, with its focus on individual human problems, is not up to this task. Instead, a more-than-individual-human-centered approach is needed that focuses on everyday practices performed by both human end-users and technologies.

This dissertation investigates the role of everyday practices with technologies in societal transitions, focusing on the case of heat pumps in the Dutch energy transition. It argues that changes in such practices are best understood as improvisations, emphasizing a co-performance of humans and technologies. This framing, inspired by theories of practice and more-than-human design, challenges the traditional view of human-centered design, which often treats everyday practices as static. Instead, it highlights the dynamic and evolving nature of these interactions, where technologies actively participate in shaping routines alongside humans. I emphasize that technologies are not merely passive tools but active participants in everyday life, co-performing alongside humans.

A key contribution of this research is the conceptualization of changes in everyday practices as improvisations, which underscores the transformative potential of friction between human and technological performances. These moments of friction, described as crises of routines, can lead to reconfigurations of practices and the emergence of enacted interfaces, reshaping how technologies are integrated into everyday life. For example, residents read indoor climate conditions from the state of plants. The dissertation offers actionable insights for designers, advocating for a proactive approach that anticipates and responds to these improvisations. Designers are encouraged to create open and adaptable technologies, strategically stage crises to provoke reflection, and engage users as co-designers in sustainable transitions. Emphasizing continuous feedback and collaboration, this approach aligns design practices with the complexities of societal transitions.

For heat pump supply side professionals, this attention to residents' improvisational activities is unfamiliar. Instead, the focus is typically on matching human needs with static technology capacities during technology development and replacement (e.g., designing heat pumps to match a 20 degrees heat provision). Consequently, acknowledging everyday improvisation may be challenging for them to adopt. An important implication of this dissertation that addresses this challenge is the encouragement of further collaboration and feedback loops. These connections should not only link users and designers, but also heat pump supply chain actors, technology end-users, designers and transition scholars.

To operationalize this conceptual framework, the dissertation introduces two design methodological proposals: the screenplay and design spaces. The proposal of the screenplay, inspired by dramaturgy, helps analyze and anticipate the temporal dimensions of everyday practices, drawing on ethnographic data and design foresight. The notion of design spaces, on the other hand, encourages critical reflection on design capacities and boundaries, fostering an openness to diverse and evolving outcomes. While these methods hold promise, future research should further explore their applicability across various transitions, technologies, and cultural contexts. By embracing the improvisational nature of everyday practices and recognizing the agency of both humans and technologies, this work advocates for a paradigm shift in design, aiming to support more responsive design practices in societal transitions.

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SUMMARY

The challenges faced by society today demand ways of thinking and designing that go beyond the individual. Climate change in particular presents uncertainty and radical societal change. Dealing with these challenges requires sustainable transitions: a restructuring of societal systems involving a broad range of actors and stakeholders, and a change to our practices and ways of living. This dissertation concerns these everyday practices, technologies that figure in these practices, and the role of design as these practices change as part of sustainable transitions.

Existing dominant approaches in design, most notably human-centered design, addresses concerns of individual humans, and technologies are designed to fit in with existing everyday practices. Societal transitions, on the other hand, address other-than-individual-human concerns and are about changes to everyday practices. There are emerging more-than-human-centered design approaches that consider everyday practices with technology in ways that highlight the dynamics and inventiveness of everyday practices, and position technologies in an active role within those everyday practices. Until now, these approaches and understandings have not been applied to the context of sustainable transitions. There is currently no coherent *conceptualization* of everyday practices with technologies in transitions that can benefit designers working in this space. This research aims to address this knowledge gap.

This research is carried out in the context of an ongoing sustainable transition. This is the heat pump transition in the Netherlands. Implementing heat pumps for residential buildings on a large scale should reduce CO2 emissions and save energy while providing comfortable indoor climate of homes. These heat pumps are replacing the gas boiler systems commonly present in most Dutch homes. The dimension of everyday practices is important in the Dutch heat pump transition as realized energy savings depend in part on everyday practices of residents in their homes. Practices such as how homes are ventilated, the thermostat settings, and even furniture layouts can influence energy performance and indoor comfort.

The main objective of this research is to develop a conceptualization of everyday practices with technologies in transitions that has actionable implications for design practices within these transitions. The research questions ask how this conceptualization can be applied to an ongoing transition in the Netherlands (RQ1), how this conceptualization might contribute to questions in other domains (transitions research and building science) (RQ2), how this conceptualization

might be operationalized for design (RQ3), and what sites of intervention follow from this conceptualization (RQ4).

The methodological approach followed in this research uses different methods to address different questions. To develop this conceptualization and apply it to the heat pump transition in the Netherlands (RQ1 and RQ2), it relies on ethnography. Design ethnographic work is carried out in eleven site-visits to heat pump enabled homes in the Netherlands. These site visits include semi-structured interviews and re-enactments of everyday practices. From this ethnographic work, a conceptualization is developed in conversation with knowledge from the domains of design, human-computer interaction, transitions, and building science. For further operationalization (RQ3 and RQ4), this research uses design activities to generate a video containing ethnographic findings and speculative design proposals, which is then used to sensitize research subjects for a follow up interview. This video presentation and interview study was done with nine professionals in the Dutch heat pump value network. This dissertation also generates intermediate level design knowledge by developing two design methodological proposals that further operationalize the conceptualization for use in design practices.

The main contributions of this research are presented in six chapters, divided in three parts.

Part I: Improvisation introduces the conceptualization of everyday practices with technologies in transitions as improvisation, that is central to this work. Chapter 2 reports on everyday practices with technologies in transitions, specifically with heat pumps in the Dutch energy transition. On this basis it introduces the main contribution developed from a design perspective: a conceptualization of everyday practices with technologies in transitions as improvisations. Following the concept of co-performance, everyday practices are performed, not only by humans, but also by technologies. Practices are performed according to what the performers consider appropriate practice. Human performers act according to what they consider 'normal' (in line with perceived societal norms) and fitting with the situation at hand. On the other hand, technologies, or artificial performers, participate in everyday practices according to the ideas of appropriate practice held by designers and technology developers, established in the design phase. As part of societal transitions towards sustainability, specific technologies, such as heat pumps are developed and distributed with the aim of reducing energy consumption or dependance on fossil fuels in everyday life. Specifically in transitions, technologies and end-users are motivated by different concerns. Ideas of appropriate practice in technology development, design and policy are mostly shaped by societal goals such as sustainability, reduced energy consumption or prevention of net congestion. On the other hand, and in potential conflict, human performers of practices (end-users) have their own, situated, everyday idea of what is appropriate practice. These end-user ideas emerge from everyday concerns and societal norms, but often not from longer-term societal concerns. In concrete situations in everyday life, differing ideas of appropriate practice between technologies and humans might result in different ideas of how to go ahead. In these cases, the underlying conflicts come to the foreground in everyday life.

Concretely, a technology might act in a way that humans do not find appropriate or fitting with the situation at hand. This results in crises of routines. Crises of routines are situations in everyday life when people do not know how to go on. Something needs to change about how technologies or humans perform their part of everyday practice so that they correspond better to ideas of appropriateness. This chapter also introduces the concept of the enacted interface: a new, persistent connection between humans and technologies. This means that the performances of humans and technologies align, connect and occur together.

Part II: Expeditions (chapters 3 and 4) introduces the conceptualization into two other fields relevant to technologies in societal transitions.

Chapter 3 revisits the ethnographic research to explore how the developed conceptualization of everyday practices from a design perspective might contribute to challenges in transitions research. This chapter introduces the concept of practice reconfigurations. These are the processes through which everyday routines change. It identifies three types of practice reconfigurations, which are necessary for, and have the potential to contribute to, the Dutch energy transition. These types are reconfigurations of knowledge, routines and material. The chapter than highlights several implications for policy and technology development in sustainability transitions in the Netherlands and beyond. It identifies several barriers to heat pump uptake in the Netherlands, and suggests an active role for the household as a source of innovation. The conceptualization contributes to challenges in transition research by highlighting the relevance of the 'micro-level' of individual relations between human individuals and technologies, and the 'meso-level' of the household. It particularly draws attention to tensions between intended and actual everyday practices, and thus highlights how the success of sustainable technologies (such as heat pumps), depends on actual everyday practices. The conceptualization highlights barriers and opportunities to realizing these predicted energy savings. Finally, a relevant insight is that 'design-like activities' also happen in technology adoption in transitions. There are similarities (in terms of creativity and innovation) between design of technologies and the uptake of those technologies in the everyday practices of the household.

Chapter 4 explores how the developed conceptualization might contribute to building science by creating an animated video, illustrating the proposed conceptualization, introducing it to heat pump supply side actors, and evaluating it with them through semi-structured interviews. This chapter identifies ten possible responses to improvisation from the technology supply side and nine motivating factors for choosing a response. It also proposes socio-technical innovations. These sites of intervention include, for example, socio-technical innovations that bridge situations of both design and use in feedback loops, or productive dialogues between technology users and technologies and designers. Other interventions could offer opportunities for experimentation, support and guiding of improvisations. The insights into the ways that supply side heat pump professionals engage with everyday practices complements existing knowledge in this domain on the influence of physical building properties. This conceptualization also highlighted the discrepancy between actual use practices and the ideas of supply chain heat pump professionals about how technologies are intended to be used. In the domain of building science, just as in the domain of societal transitions, this chapter reveals similarities between technology development and use, sharing features of creativity and innovation.

Part III: Representations proposes two visual methods for design that highlight and support the analysis of features of everyday practices relevant to the conceptualization.

Chapter 5 introduces the design methodological proposal of the screenplay to represent and annotate improvisational co-performances. The visual layout and vocabulary of slug lines and narrative descriptions used in the screenplay, represent the temporal dimension of everyday practices. They enable a way to visualize, represent and communicate how everyday practices change and take place over different time spans. The second dimension of everyday practices with technologies represented in the screenplay, is that of ideas of appropriate practice. Through the use of parentheticals indicating the motivation, logic or know-how behind the actions of both technologies and humans, one can represent ideas of appropriate practice motivating these actions, and also describe how these ideas change. Chapter 5 concludes that the screenplay is an effective vocabulary for reading everyday practices with technologies, and specifically enacted interfaces. It also proposes that this screenplay might be used, not only to represent and analyze past performances of practices (from ethnographic data), but also to anticipate and envision future everyday practices in design processes.

Chapter 6 introduces a second design methodological proposal. The idea of design spaces is explored to visualize, analyze and anticipate the design capacities of designers, users and technologies, which are confined by what is considered appropriate practice. With time on the one axis, and the size of design spaces on the other, this visualization presents an opportunity to make design capacities explicit. Design spaces, visualized as areas with boundaries, located in design and use situations, provide a way to represent and compare these design capacities. Where the boundaries of these spaces are placed, indicates the range of what is considered an acceptable design outcome. In the developed conceptualization, this boundary is, among other things, determined by appropriate practice. Thus, mapping the design spaces is proposed as a way for designers to consider, communicate and anticipate appropriate design decisions, even when design happens outside formal design or technology development situations.

The final chapter 7 reflects on the main contribution of this dissertation and the research questions. It highlights how this research has advocated for a shift from human-centered design to a more-than-individual-human-centered approach, which embraces the improvisational nature of everyday life and the agency of both humans and technologies. This final chapter also draws out some further reflections on interdisciplinary research and the value of a design research perspective. It summarizes sites of intervention for design in transitions in three categories: setting the stage for improvisation, responding to improvisation, and facilitating responsiveness to improvisation. This chapter also draws out some further implications of the findings. It suggests for policy to shift focus from technology roll-out to supporting practice reconfigurations. For technology development it highlights new relations among value chain actors. And for households it underscores the critical creative and innovating role that these can play in sustainable transitions. The chapter offers some reflections on the methodological choices followed in this research. Finally, it addresses some of the limitations of this work and conclude with suggestions for future research. This future work should prioritize continuous feedback between everyday practices and design, a collaboration of academia and design practice, and may develop a more general framework for design in transitions.

SAMENVATTING

De uitdagingen waar de maatschappij vandaag de dag voor staat, vragen om manieren van denken en ontwerpen die verder gaan dan het individu. Vooral klimaatverandering brengt onzekerheid en radicale maatschappelijke veranderingen met zich mee. Om met deze uitdagingen om te gaan zijn duurzame transities nodig: een herstructurering van maatschappelijke systemen waarbij een breed scala aan actoren en belanghebbenden betrokken is, en een verandering van onze praktijken en manieren van leven. Dit proefschrift gaat over deze alledaagse praktijken, technologieën die een rol spelen in deze praktijken, en de rol van ontwerpen als deze praktijken veranderen als onderdeel van duurzame transities.

Bestaande dominante benaderingen in ontwerpen, met name *human-centered design*, richten zich op de belangen van individuele mensen, en technologieën worden ontworpen om te passen in bestaande alledaagse praktijken. Maatschappelijke transities richten zich daarentegen op andere dan individueel-menselijke belangen en gaan over veranderingen in alledaagse praktijken. Er zijn nieuwe, *more-than-human-centered* (meer-dan-menselijke) ontwerpbenaderingen in opkomst die alledaagse praktijken met technologie beschouwen op een manier die de dynamiek en vindingrijkheid van alledaagse praktijken benadrukt en technologieën een actieve rol geeft binnen die alledaagse praktijken. Tot nu toe zijn deze benaderingen en inzichten niet toegepast op de context van duurzame transities. Er is momenteel geen samenhangende *conceptualisering* van alledaagse praktijken met technologieën in transities waar ontwerpers die in deze ruimte werken hun voordeel mee kunnen doen. Dit onderzoek heeft als doel deze kennisleemte op te vullen.

Dit onderzoek wordt uitgevoerd in de context van een duurzame transitie die op dit moment aan de gang is. Dit is de warmtepomptransitie in Nederland. Door warmtepompen op grote schaal toe te passen in woongebouwen moet de CO2-uitstoot worden verminderd en energie worden bespaard, terwijl het binnenklimaat van woningen comfortabel blijft. Deze warmtepompen vervangen de cv-ketels die in de meeste Nederlandse woningen aanwezig zijn. De dimensie van alledaagse praktijken is belangrijk in de Nederlandse warmtepomptransitie, omdat gerealiseerde energiebesparingen deels afhangen van de alledaagse praktijken van bewoners in hun huizen. Praktijken zoals de manier waarop woningen worden geventileerd, de thermostaatinstellingen en zelfs de indeling van het meubilair kunnen de energieprestaties en het comfort binnenshuis beïnvloeden.

Het hoofddoel van dit onderzoek is: het ontwikkelen van een conceptualisatie van alledaagse praktijken met technologieën in transities die bruikbare implicaties heeft voor ontwerppraktijken binnen deze transities. De onderzoeksvragen zijn: hoe deze conceptualisatie kan worden toegepast op een transitie in Nederland (vraag 1), hoe deze conceptualisatie kan bijdragen aan vragen in andere domeinen (transitieonderzoek en bouwwetenschap (*building science*)) (vraag 2), hoe deze conceptualisatie kan worden geoperationaliseerd voor ontwerp (vraag 3), en welke richtingen voor interventie uit deze conceptualisatie volgen (vraag 4).

De methodologische benadering die in dit onderzoek is gevolgd, maakt gebruik van verschillende methoden om verschillende vragen te beantwoorden. Om deze conceptualisatie te ontwikkelen en toe te passen op de warmtepomptransitie in Nederland (vraag 1 en 2), wordt gebruik gemaakt van etnografie. Ontwerpetnografisch onderzoek is uitgevoerd in elf locatiebezoeken aan warmtepompwoningen in Nederland. Deze bezoeken op locatie omvatten semigestructureerde interviews en het heropvoeren (*re-enactment)* van alledaagse praktijken. Op basis van dit etnografische werk is een conceptualisatie ontwikkeld in gesprek met kennis uit de domeinen ontwerpen, mens-computer interactie, transitieonderzoek en bouwwetenschap. Voor verdere operationalisering (vraag 3 en 4) gebruikt dit onderzoek ontwerpactiviteiten om een video te genereren met etnografische bevindingen en speculatieve ontwerpvoorstellen, welke vervolgens wordt gebruikt om de proefpersonen te sensibiliseren voor een vervolginterview. Deze videopresentatie en interviewstudie is uitgevoerd met negen professionals in het Nederlandse warmtepomp-waarde-netwerk. Dit proefschrift genereert ook ontwerpkennis op intermediair niveau door twee ontwerpmethodologische voorstellen te ontwikkelen die de conceptualisatie verder operationaliseren voor gebruik in de ontwerppraktijk.

De belangrijkste bijdragen van dit onderzoek worden gepresenteerd in zes hoofdstukken, onderverdeeld in drie delen.

Deel I: Improvisatie introduceert de conceptualisering van alledaagse praktijken met technologieën in transities als improvisatie, die centraal staat in dit werk. Hoofdstuk 2 doet verslag van alledaagse praktijken met technologieën in transities, specifiek met warmtepompen in de Nederlandse energietransitie. Op basis hiervan introduceert het de belangrijkste bijdrage van dit onderzoek die is ontwikkeld vanuit een ontwerpperspectief: een conceptualisering van alledaagse praktijken met technologieën in transities als improvisaties. Volgens het concept van *co-performance* worden alledaagse praktijken uitgevoerd, niet alleen door mensen, maar ook door technologieën. Praktijken worden uitgevoerd zoals de uitvoerders *passend* beschouwen. Menselijke uitvoerders handelen volgens wat zij 'normaal' vinden (in lijn met waargenomen maatschappelijke normen) en *passend* bij de situatie in kwestie. Aan de andere kant nemen technologieën, of kunstmatige uitvoerders, deel aan alledaagse praktijken zoals ontwerpers en technologieontwikkelaars *passend* vinden, vastgesteld in de ontwerpfase. Als onderdeel van maatschappelijke transities naar duurzaamheid worden specifieke technologieën, zoals warmtepompen, ontwikkeld en gedistribueerd met als doel het energieverbruik of de afhankelijkheid van fossiele brandstoffen in het dagelijks leven te verminderen. Juist in transities worden technologieën en eindgebruikers gemotiveerd door verschillende belangen. Ideeën over passende praktijken in technologieontwikkeling, -ontwerp en -beleid worden meestal gevormd door maatschappelijke doelen zoals duurzaamheid, minder energieverbruik of het voorkomen van netto congestie. Aan de andere kant, en potentieel conflicterend met deze doelen, hebben menselijke uitvoerders van praktijken (eindgebruikers) hun eigen, gesitueerde, alledaagse idee van wat een passende praktijk is. Deze ideeën van eindgebruikers komen voort uit alledaagse behoeften en maatschappelijke normen, maar vaak niet uit maatschappelijke zorgen op langere termijn. In concrete situaties in het dagelijkse leven kunnen verschillende ideeën over gepaste praktijken tussen technologieën en mensen resulteren in verschillende ideeën over hoe verder te gaan. In deze gevallen treden de onderliggende conflicten op de voorgrond in het dagelijks leven. Concreet kan een technologie handelen op een manier die mensen niet gepast vinden in de betreffende situatie. Dit resulteert in *routinecrises*. Routinecrises zijn situaties in het dagelijks leven waarin mensen niet weten hoe ze verder moeten. Er moet iets veranderen aan de manier waarop technologieën of mensen hun deel van de dagelijkse praktijk uitvoeren, zodat ze beter overeenkomen met ideeën over *passendheid*. Dit hoofdstuk introduceert ook het concept van de *enacted interface*: een nieuwe, blijvende verbinding tussen mensen en technologieën. Een *enacted interface* betekent dat de *co-performances* van mensen en technologieën op elkaar aansluiten, met elkaar verbonden zijn en samen optreden.

Deel II: Expedities (hoofdstuk 3 en 4) introduceert de conceptualisatie in twee andere gebieden die relevant zijn voor technologieën in maatschappelijke transities.

Hoofdstuk 3 gaat terug naar het etnografisch onderzoek om te verkennen hoe de ontwikkelde conceptualisatie van alledaagse praktijken vanuit een ontwerpperspectief kan bijdragen aan uitdagingen in transitieonderzoek. Dit hoofdstuk introduceert het concept van *praktijkreconfiguraties*. Dit zijn de processen waardoor alledaagse praktijken veranderen. Het identificeert drie typen praktijkreconfiguraties die nodig zijn voor, en de potentie hebben om bij te dragen aan, de Nederlandse energietransitie. Deze typen zijn reconfiguraties van *kennis*, van *routines* en van *fysieke* aspecten. Het hoofdstuk belicht vervolgens verschillende implicaties voor beleid en technologieontwikkeling in duurzaamheidstransities in Nederland en daarbuiten. Het identificeert verschillende barrières voor de acceptatie van warmtepompen in Nederland en suggereert een actieve rol voor het huishouden als bron van innovatie. De conceptualisering draagt bij aan uitdagingen in transitieonderzoek door de relevantie te benadrukken van het 'microniveau' van individuele relaties tussen menselijke individuen en technologieën, en het 'mesoniveau' van het huishouden. Het vestigt in het bijzonder de aandacht op spanningen tussen bedoelde en feitelijke alledaagse praktijken, en benadrukt zo hoe het succes van duurzame technologieën (zoals warmtepompen) afhangt van de feitelijke alledaagse praktijken. De conceptualisatie belicht barrières en mogelijkheden om deze voorspelde energiebesparingen te realiseren. Tot slot is een relevant inzicht dat 'ontwerpachtige activiteiten' ook plaatsvinden bij de adoptie van technologie in transities. Er zijn overeenkomsten (in termen van creativiteit en innovatie) tussen het ontwerpen van technologieën en de toepassing van die technologieën in de dagelijkse praktijk van het huishouden.

Hoofdstuk 4 onderzoekt hoe de ontwikkelde conceptualisatie zou kunnen bijdragen aan de bouwwetenschap door een animatievideo te maken die de voorgestelde conceptualisatie illustreert, deze te introduceren bij actoren in de *aanbodzijde* van warmtepompen en deze met hen te evalueren door middel van semigestructureerde interviews. Dit hoofdstuk identificeert tien mogelijke antwoorden (*responses*) op improvisatie van de kant van de technologieleverancier en negen motiverende factoren voor het kiezen van een antwoord. Er worden ook socio-technische innovaties voorgesteld. Deze richtingen voor interventie omvatten bijvoorbeeld socio-technische innovaties die een brug slaan tussen situaties van ontwerp en gebruik in de vorm van feedbacklussen, of productieve dialogen tussen technologiegebruikers, technologieën en ontwerpers. Andere interventies zouden mogelijkheden kunnen bieden voor experimenten, ondersteuning en begeleiding van improvisaties. De inzichten in de manieren waarop warmtepompprofessionals aan de aanbodzijde zich bezighouden met alledaagse praktijken vormen een aanvulling op bestaande kennis op dit gebied over de invloed van fysieke gebouweigenschappen. Deze conceptualisatie benadrukte ook de discrepantie tussen feitelijke gebruikspraktijken en de ideeën van warmtepompprofessionals aan de aanbodzijde over hoe technologieën bedoeld zijn om gebruikt te worden. Net als in het domein van maatschappelijke transities, benadrukt dit hoofdstuk voor de bouwwetenschap de overeenkomsten tussen de ontwikkeling en het gebruik van technologie, die kenmerken van creativiteit en innovatie delen.

Deel III: Representaties stelt twee visuele ontwerpmethoden voor. Deze benadrukken kenmerken van alledaagse praktijken die relevant zijn voor de conceptualisatie.

Hoofdstuk 5 introduceert het ontwerpmethodologische voorstel van het *scenario* om improvisatorische co-performances weer te geven en te annoteren. De visuele lay-out en het vocabulaire van *sluglines* en *narrative description* die in het scenario worden gebruikt, representeren de tijdsdimensie van alledaagse praktijken. Ze maken het mogelijk om te visualiseren, te representeren en te communiceren over hoe alledaagse praktijken veranderen en plaatsvinden in verschillende tijdsperioden. De tweede dimensie van alledaagse praktijken met technologieën in het scenario is die van ideeën over *passendheid* van praktijken. Door het gebruik van *parentheticals* die de motivatie, logica of *knowhow* achter de acties van zowel technologieën als mensen aangeven, kan men ideeën van *passendheid* weergeven die deze acties motiveren, en ook beschrijven hoe deze ideeën veranderen. Hoofdstuk 5 concludeert dat het *filmscenario* een effectief vocabulaire is voor het lezen van alledaagse praktijken met technologieën, en specifiek *enacted interfaces*. Er wordt ook voorgesteld dat dit scenario niet alleen kan worden gebruikt voor het representeren en analyseren van eerder uitgevoerde dagelijkse praktijken (op basis van bijvoorbeeld etnografische data), maar ook voor het anticiperen op, en voorzien van toekomstige alledaagse praktijken in ontwerpprocessen.

Hoofdstuk 6 introduceert een tweede ontwerpmethodologisch voorstel. Het idee van ontwerpruimte (*design spaces*) wordt verkend om de ontwerpcapaciteiten van ontwerpers, gebruikers en technologieën te visualiseren, te analyseren en hierop te anticiperen. Ontwerpruimtes worden begrensd door wat als een passende praktijk wordt beschouwd. Met tijd op de ene as en de grootte van ontwerpruimtes op de andere, biedt deze visualisatie de mogelijkheid om ontwerpcapaciteiten expliciet te maken. Ontwerpruimtes, gevisualiseerd als gebieden met grenzen, te vinden in ontwerp- en gebruikssituaties, bieden een manier om deze ontwerpcapaciteiten weer te geven en te vergelijken. Waar de grenzen van deze ruimten worden geplaatst, geeft het bereik aan van wat wordt beschouwd als een acceptabel ontwerpresultaat. In de ontwikkelde conceptualisatie wordt deze grens onder andere bepaald door de *passendheid* van praktijken. Het in kaart brengen van de ontwerpruimten wordt dus voorgesteld als een manier voor ontwerpers om passende ontwerpbeslissingen te overwegen, erover te communiceren en erop te anticiperen; zelfs wanneer het ontwerp plaatsvindt buiten formele ontwerp- of technologieontwikkelingssituaties.

Hoofdstuk 7 reflecteert op de belangrijkste bijdrage van dit proefschrift en de onderzoeksvragen. Het benadrukt hoe dit onderzoek heeft gepleit voor een verschuiving van mensgericht ontwerpen naar een *more-than-human-centered* (meer-dan-menselijke) benadering, die de improviserende aard van het alledaagse leven en de *agency* van zowel mensen als technologieën omarmt. Dit laatste hoofdstuk bevat ook enkele verdere reflecties over interdisciplinair onderzoek, ontwerpetnografisch onderzoek, en de waarde van een ontwerpend onderzoeksperspectief. Het geeft een overzicht van richtingen voor interventie voor ontwerp in transities in drie categorieën: de *weg bereiden voor* improvisatie, *reageren op* improvisatie, en *respons* op improvisatie *faciliteren*. Dit hoofdstuk schetst ook enkele verdere implicaties van de bevindingen. Voor *beleid* suggereert het om de focus te verleggen van het uitrollen van technologie naar het ondersteunen van reconfiguraties van dagelijkse praktijken. Voor de *ontwikkeling van technologie* benadrukt het nieuwe relaties tussen actoren in de waardeketen. En voor *huishoudens* onderstreept het de cruciale creatieve en innoverende rol die zij kunnen spelen in duurzame transities. Het hoofdstuk biedt enkele reflecties op de methodologische keuzes die in dit onderzoek zijn gemaakt. Tot slot wordt ingegaan op enkele beperkingen van dit werk en wordt afgesloten met suggesties voor toekomstig onderzoek. Dit toekomstige werk zou prioriteit moeten geven aan voortdurende feedback tussen ontwerpen en dagelijkse praktijken, een samenwerking tussen de academische wereld en de ontwerppraktijk, en zou een meer algemeen kader kunnen ontwikkelen voor ontwerpen in transities.

ACKNOWLEDGEMENTS

Without the care and support of many people, this dissertation would not exist. Here, I want to acknowledge everyone who made this PhD and life next to it possible and enjoyable.

First, I would like to express my heartfelt gratitude to my supervisory team. Bringing your diverse and multidisciplinary strengths together in a strong team was only possible thanks to your openness and ability to truly listen. This created the fertile ground for many discussions of which I only had to pick the fruits, which I will carry with me for a long time. **Stella**, thank you for choosing me for this project. Thank you, for supporting my choices with curiosity and genuine interest in where they might lead, and for granting me the freedom and flexibility to grow. Your guidance on academic nuances and tricks of the trade has been invaluable. **Alessandro**, thank you for your steady encouragement and, in these last stages, pushing me out of the PhD. Your practical pragmatic advice and sharp critical thinking challenged me and pushed me to grow. **Elisa**, thank you for your generosity and visionary thinking. I am forever grateful for the chance to share in the way you write and think. Your academic creativity and the ability to carefully articulate those sparks of insight helped me see new possibilities, only some of which we explored.

I'm especially thankful to my closest colleagues and friends, Laura and Hannah. Who knew that what started as a way to ease the isolation of COVID in our small cohort would turn into real friendship, built on sharing the ups and downs, the fun times and the frustrations. To me, the companionship we found along the way means more than the academic outcome of these long four years. **Laura**, thank you for being the welcome distraction always happy to pull me out of my work. You were there through the tough times, and sharing the highs and lows of parenthood with you made this dual employment more manageable. **Hannah**, thank you for your generosity and kindness. I really appreciate how you always seemed to figure things out just a bit before I did. Sharing doubts and struggles with you, made this whole process a lot less overwhelming. Of course, also thanks to your other halves and your growing families, **Job, Finn, Ben**.

A big thank you to all current and former members of StudioLab for giving me an academic and creative home over the years. The shared lunches, shared desk spaces, informal chats, support, and guidance created a uniquely fertile environment for design, learning, and camaraderie. Maybe one day I'll stop showing up at StudioLab every now and then, just not yet. My thanks are due to **Aadjan** for the support and being the most trustworthy central figure in Studiolab. **Anna Louisa**, thanks for your passion for a better world and being an excellent example of a healthy work-life balance. **Boudewijn**, thank you so much for the humble mentorship over all these years. **Iohanna**, thank you for being the inspirational example showing what is possible if you allow creativity and originality to flourish. Thanks to **Dajung** for all the long enlightening conversations (one day we will write that paper together). **Cais**, for your strength and perseverance. **Yuxi**, for staying true to what you came to do. **Zhuochao** for sharing in the fun we had in Milano and **Froukje** for being a great deskmate. Thank you, **Abhi**, **Alev**, **Alessandro**, **Dave**, **Davide**, **Deger**, **Enne**, **Gijs**, **Gül**, **Haian**, **Ianus**, **Jasper**, **Jerry**, **Karin**, **Lye**, **Mahan**, **Maria Luce**, **Marian**, **Marina**, **Marco**, **Martin**, **Mert**, **Mireia**, **Natalia**, **Nazli**, **Patrizia**, **Pelin**, **PJ**, **Razieh**, **Roy**, **Sacha**, **Sam**, **Sofie**, **Susanne**, **Thomas**, **Timothy**, **Willem**, **Xueliang**, and all StudioLab colleagues.

Of course, also a big thank you to the other faculty colleagues who I had the pleasure to collaborate with in education, research and design, or run into at borrels and activities, specifically: **Alice**, **Elisabeth**, **Jered**, **Kars**, **Laurens**, **Mariet**, **Samuel**, **Soyeon**, **Vera** and **Wasabii**. **Jan Willem**, thanks for the illustrations illuminating the cover of this dissertation.

Thanks to the IDE students I was lucky enough to mentor on their graduation projects. You were a pleasure to work with and have inspired me with your enthusiasm, originality and curiosity. **Jizhou**, **Anouk**, **Mare**, **Yichen** (thank you for your help with video animation and happy you continue your journey at TU Delft), **Caspar** (looking forward to our continued collaboration).

I'd like to sincerely thank the colleagues from the HCD secretariat for your invaluable support. Your availability, patience, and efficiency in handling practical matters made a real difference throughout this process.

I would also like to thank the colleagues from beyond the faculty who I met working in energy and sustainability. In particular, **Prateek Wahi**, **Sarah Marchionda**, **Simon Hageman**, **Luyi Xu**, **Olivia Guerra-Santin, Thaleia Konstantinou, Henk Visser, Laure Itard**. Here, I would also like to thank industry collaborators from the IEBB consortium and beyond for their generous listening and sharing of insights.

Thank you to my committee members, whose work I deeply respect, for taking the time to review my thesis and for being part of this important milestone.

This dissertation also has the invisible touches of my new colleagues. Thank you, Team Hoopgedreven, **Jan Jorrit**, **Louti**, **Egbert**, **Johan**, **Julieta**, **Mark**, **Alfons**, **Ernst**, **Marlon**, for giving me the space to finish this work and the joy of starting new things.

This work is better because I interacted with people with little interest in the work. I have been fortunate with friends who know when and when not to ask how the PhD is going, celebrating with me and providing much-needed distractions. Thank you, **Angeline**, **Annemarie S.**, **Caroline**, **Edward, Eelco**, **Elijne**, **Frans**, **Frederik**, **Frouwko, Geerd**, **Hans**, **Inge H.,** **Jaap**, **Jasper**, **Jeroen**, **Johanna**, **Jonard**, **Jos**, **Marc**, **Marten, Matthijs**, **Pieter van der G.**, **Pieter van der K.**, **Pieter van P.**, **Rick**, **Robin**, **Roeland**, **Simon**, **Vincent**, **Willem-Jan** and many more.

Pa en **ma**, zonder jullie steun was dit niet mogelijk geweest. Ik hoop dat dit werk iets reflecteert van de integriteit en de onbaatzuchtigheid die jullie mij hebben meegegeven. Mijn broers en zussen, schoonzussen en zwagers, **Jacolien, Maarten, Bertine, Dirk, Marcel, Eline, Willem,** en jullie gezinnen, bedankt voor de belangstelling en de hulp om dingen in perspectief te zien. Mijn **schoonouders, Jan-Willem, Annemarie, Laura,** jullie warmte en aanmoediging maakte het makkelijker.

Reinoud, delen van dit proefschrift zijn geschreven terwijl jij op mijn schoot sliep, terwijl je nu al geen moment meer stilligt. Jouw nieuwsgierige blik leert mij beter kijken. Je vervult me met veel meer trots dan dit proefschrift ooit zal doen. Lieve **Inge**, je bent mijn voorbeeld in moed en openheid. Dank voor al die momenten dat je erbij was en naast mij stond. Dank dat je rekening houdt met de hoeveelheid koffie die ik op heb. Ik kijk ernaar uit om veel meer tijd met jou door te brengen. Deze woorden zijn maar ontoereikende gereedschappen. Het punt is dat ik van je hou.

Evert van Beek

Delft, 10 mei 2025

ABOUT THE AUTHOR

Evert van Beek – van der Knijff was born 1992 in Barneveld, the Netherlands. He obtained a bachelor's degree in Industrial Design Engineering, and a master's degree in Design for Interaction, both from Delft University of Technology. His master thesis concerned human - guide dog interactions as an analogy for smart objects. After his graduation, Evert worked as a researcher at Mintlab KU Leuven, designing, prototyping and leading co-design workshops with academic and industrial partners. After this, he was active as a freelance researcher and designer.

Evert started his PhD in 2020 on the role of household interactions with heat pumps in societal transitions, a project situated in the RVO funded consortium project Integrale Energietransitie Bestaande Bouw. Evert is active in academic communities of design, HCI, transitions and sustainability, contributing to academic workshops, book chapters and acting as a reviewer. He is an experienced teacher in and about the field of design research, developing courses and supervising master students.

Currently, Evert is a postdoctoral researcher on hope in transitions at Vrije Universiteit Amsterdam. He lives in Delft, with his spouse Inge, and their son Reinoud.

LIST OF PUBLICATIONS

Peer reviewed publications included in this dissertation (chapters 2-6)

van Beek, E., Giaccardi, E., Boess, S., & Bozzon, A. (2023b). The everyday enactment of interfaces: A study of crises and conflicts in the more-than-human home. *Human–Computer Interaction*, *40*(1–4), 221–248. https://doi.org/10.1080/07370024.2023.2283536

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Datasets

van Beek, E., Boess, S., Giaccardi, E., & Bozzon, A. (2025). *Data and materials underlying the publications: Practice reconfigurations around heat pumps in and beyond Dutch households and The everyday enactment of interfaces: A study of crises and conflicts in the more-than-human home* [Dataset]. 4TU.ResearchData. https://doi.org/10.4121/32096b27-a9eb-4bc7-aaf2-73664241035a

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The challenges faced by society today demand ways of thinking and designing that go beyond the individual. This dissertation is concerned with sustainable transitions, and focuses on everyday practices, technologies within those practices, and the role of design. Empirically, the research focuses on the transition from gas boilers to heat pumps in Dutch homes. Implementing heat pumps for residential buildings on a large scale should reduce CO2 emissions and save energy while providing comfortable indoor climate of homes. However, in everyday life in households, heat pumps are often not used as the technology developers intended. Ethnography, design research and interviews with value chain professionals are used to gather data and better understand how everyday practices with technologies are performed and understood. Based on this analysis, the dissertation questions dominant human-centered design approaches, which prioritize individual users and align with current practices, arguing that they fall short in supporting societal transitions. This work takes steps towards a more-than-individual-human-centered approach, which embraces the improvisational nature of everyday life and the co-performance of humans and technologies, with the goal of benefitting design work within sustainable transitions.

DESIGNING WITH IMPROVISATIONS

TU Delft Delft University of Technology