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DESIGNING SPECULATIVE ARTIFACTS

– Using Real-World Patterns to Inform HCI

Designing Speculative Artifacts

Using Real-World Patterns to Inform HCI

Dissertation

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Abstract

In recent decades, Mark Weiser's [132] vision of ubiquitous computing has become today's reality through embedded electronics, the rise of machine learning, and the proliferation of wireless Internet access. This development brings not only opportunities but also new challenges for the Human-Computer Interaction (HCI) community. Technology, for example, is (1) entering novel application scenarios and pristine interaction environments, (2) leaving the screen and conquering the physical world, and (3) changing the previous tool-like nature of computers to social, self-learning, and pro-active entities. As a result, there are no already established interaction paradigms, metaphors, and design strategies for designing such systems.

Thus, HCI faces questions about the interaction design in the context of embedded systems and novel materials, the conceptualization of intelligent systems in everyday environments, and, subsequently, the consequences on human-technology relations.

To approach such questions, a standard tool in HCI research is the human-centered design process, which creates knowledge about user needs and considers user perspectives to inform design decisions. Observations and interviews are used to understand the context, workflow, or tools, before developing ideas and concepts for technological improvements or solutions. This process has proven to be effective when dealing with matters familiar to users, such as their workplaces, leading to improved workflows and experiences. However, it remains open how design can be grounded if future technologies result in unfamiliar situations. When people can no longer contribute with their domain knowledge, what are novel interaction concepts, paradigms, and designs based on?

To tackle these problems, I present and discuss a programmatic design approach to generate original design ideas and concepts. This approach builds on Speculative and Critical Design practices within the HCI context. The main idea central to this work is to create designs using **real-world patterns to inform HCI** since these patterns still comply with users' prior knowledge, experiences, and perception of fundamental social or natural principles. Such Real-World Patterns (RWP) can be familiar metaphors, morphologies, or mental models – e.g., understanding causality in the physical world or knowing the basic working principles of musical instruments. These patterns are chosen and then transferred into designs to meet or contradict users' expectations of the technology in order to create confrontational situations in which new perspectives are opened up. Based on the confrontation with the **speculative artifacts**, implications and requirements are deduced, which in reverse can be applied to future technologies.

The projects presented apply this approach in various HCI research domains, including human-robot interaction, new interfaces for musical expression, and deformable and flexible interfaces. In this dissertation, I reflect on the approach using three questions: (**Q1**) How does the use of RWPs complement the Research through Design practice?; (**Q2**) How can RWPs be instrumentalized in the design of HCI systems?; and (**Q3**) How does the use of RWPs in

design affect the relation between humans and technology?

This thesis contributes (1) an overview of the approach as well as three perspectives which are instrumental in understanding and applying RWPs in the design of HCI, (2) eight speculative artifacts, which exemplify the approach, (3) theories and concepts inspired by the used RWPs, and (4) empirical knowledge deduced from the associated studies and surveys.

Zusammenfassung

In den letzten Jahrzehnten ist Mark Weisers [132] Vision des *Ubiquitous Computing* durch eingebettete Systeme, den Aufstieg künstlicher Intelligenz und die Verbreitung des drahtlosen Internetzugangs zur heutigen Lebensrealität geworden. Diese Entwicklung bringt nicht nur Chancen, sondern auch neue Herausforderungen für die Human Computer Interaction (HCI) Community mit sich. Technologien dringen bspw. in neuartige Anwendungsszenarien und noch unberührte Interaktionsumgebungen ein, verlassen den Bildschirm und erobern die physische Welt und verändern so den bisherigen werkzeugartigen Charakter von Computern zu sozialen, selbstlernenden und proaktiven Entitäten. Infolgedessen gibt es keine bereits etablierten Interaktionsparadigmen, Metaphern und Designstrategien, auf die für die Gestaltung solcher Systeme zurückgegriffen werden könnte.

Für die HCI stellen sich daher Fragen zur Interaktionsgestaltung im Kontext eingebetteter Systeme und neuartiger Materialien, zur Konzeptualisierung intelligenter Maschinen in Alltagsumgebungen und folglich zu den Auswirkungen auf die Beziehung, in der Mensch und Technologie zueinander stehen.

Um sich solchen Fragen zu nähern, ist in der HCI der *Human-Centered Design* Prozess eine verbreitete Vorgehensweise, die Erkenntnisse über die Bedürfnisse der Benutzer:innen schafft und deren Perspektive bei Designentscheidungen berücksichtigt. Beobachtungen und Interviews werden genutzt, um den Kontext, die Arbeitsabläufe oder Werkzeuge zu verstehen, bevor Ideen und Konzepte für technische Lösungen entwickelt werden. Dieses Vorgehen hat sich als effektiv erwiesen und führt zu Verbesserungen von Technologien, solange die betreffenden Situationen den Nutzer:innen vertraut sind. Offen bleibt jedoch, worauf Design-Konzepte bauen können, wenn zukünftige Technologien zu ungewohnten Situationen führen. Worauf basieren neuartige Interaktionskonzepte, Paradigmen und Entwürfe, wenn Menschen nicht mehr mit ihrem Fachwissen und Erfahrungen beitragen können?

Um diese Problematik anzugehen, präsentiere und diskutiere ich in dieser Dissertation einen programmatischen Ansatz, um neuartige Designideen und -konzepte zu entwickeln. Dieser baut auf den Praktiken des spekulativen und kritischen Designs im HCI-Kontext auf. Im Mittelpunkt steht die Entwicklung von Designs unter Verwendung von Mustern aus der realen Welt, da diese das Vorwissen der Nutzer:innen sowie soziale und natürliche Prinzipien einbeziehen. Bei solchen Real-World Patterns (RWP) kann es sich um vertraute Metaphern, Morphologien oder mentale Modelle handeln, bspw. um das Verständnis von Kausalität in der physischen Welt oder um die Kenntnis der grundlegenden Funktionsprinzipien von Musikinstrumenten. Potentielle Muster werden ausgewählt und derart in Entwürfe übertragen, dass die Erwartungen der Nutzer:innen an die Technologie erfüllt oder ihnen widersprochen wird. So werden konfrontative Situationen geschaffen, in denen sich neue Perspektiven eröffnen. Aus der Konfrontation mit den spekulativen Artefakten werden Implikationen und Anforderungen abgeleitet, die sich im Umkehrschluss auf zukünftige Technologien anwenden lassen.

Die vorgestellten Projekte wenden diesen Ansatz in verschiedenen HCI-Forschungsbereichen an, unter anderem in der Mensch-Roboter-Interaktion, im Kontext neuer Schnittstellen für die musikalische Interaktion, sowie für deformierbare und flexible Schnittstellen. In dieser Dissertation reflektiere ich den Ansatz anhand dreier Fragen: (**Q1**) Wie ergänzt der Einsatz von RWPs die *Research through Design* Praxis?; (**Q2**) Wie können RWPs für das Design von HCI-Systemen instrumentalisiert werden?; und (**Q3**) Wie beeinflusst der Einsatz von RWPs die Beziehung zwischen Mensch und Technologie?

Der Beitrag dieser Arbeit liegt in (1) einem Überblick über den Ansatz sowie in den drei Perspektiven, die für das Verständnis und die Anwendung von RWPs in der Gestaltung von HCI maßgeblich sind, (2) den acht spekulativen Artefakten, die den Ansatz beispielhaft darstellen, (3) den Theorien und Konzepten, die von den verwendeten RWPs inspiriert sind, und (4) den empirischen Erkenntnissen, die aus den zugehörigen Studien und Umfragen abgeleitet wurden.

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1
INTRODUCTION

Nowadays, the boundaries between technology and humans are increasingly fuzzy: natural language processing, social robotics, artificial intelligence, cyberphysical systems, virtual reality, augmented reality or neuro-implants are all probing the limits of where the human ends and technology starts.

– Christopher Frauenberger [43]

1.1 Thesis Statement

Human Computer Interaction (HCI) today is confronted with major technological developments and innovations that can fundamentally change the way we will interact with computer systems in the future. Some of these technologies are already on the verge; others are rather vague ideas than technologies that have already been conclusively defined and implemented. These include products that use blockchain technology [35], image recognition via machine learning [99], bio-signal processing [4], or anthropomorphized personal assistants [141]. Other technologies, such as public autonomous-systems in the form of urban robots [134], fully autonomous cars [75], or a new scale of computing power through quantum computing [136], are only a foretaste of what is yet to come.

As a result of this development, HCI faces many new exciting opportunities but also significant questions, particularly for creating novel interaction paradigms, concepts, and interfaces. However, HCI is further confronted with fundamental challenges and, thus, has to consider societal and ethical implications regarding the impact of these developments on people and society. To address such challenges, researchers from the HCI domain increasingly incorporate research methods and approaches from the fields of critical [6, 9, 104] and speculative design [3, 34, 123] into their research practice, which go beyond the established User-Centered Design (UCD) process [129]. These approaches allow researchers to design not only for today's comprehensible user needs but also to consider possible future developments, societal issues, and potential paradigm shifts and use them as a starting point or frame of reference for their research. As Fallman [39] already emphasized, one "of the core activities in contemporary HCI is to conceive, propose, design, and implement new technologies [...] through which a researcher's ideas for novel and alternative solutions can materialize and take on concrete shape" [39]. In both speculative and user-centered processes, the design and creation of experiential artifacts are central to the knowledge production of such research. This transfer into objects is how ideas and concepts become tangible, understandable, and replicable in the everyday lives of humans.

In this thesis, I present a collection of my research projects and discuss how the *use of real-world patterns* can manifest via individual forms of analogical reasoning in the form of *speculative artifacts*. Instrumentalizing these manifestations in the design process *to inform HCI* systems that address the various purposes within the context of the Research through Design (RtD) practice is, in short, the main objective of this thesis.

1.2 Definitions

In the following, I will elaborate on the key terms used in the thesis title. To do so, I focus on the three keywords: Artifact, Speculative, and Real-World Pattern.

For the scope of the thesis, I use the term **artifact** analogously to Buchenau's and Suri's understanding of artifacts in the context of experience prototyping [22]. In that sense, artifacts are conceptualized as human-made objects which are the "product of human workmanship or any object modified by man" [70]. This understanding is more exclusive since other definitions, e.g., used by Alan Dix, comprehend artifacts more generally as "human-created systems [...] that mediate human activity"[1] which includes intangible products of human culture such as language, mathematics, or music beside physical objects.

The **speculative** aspect of these artifacts refers to critical and design-oriented research practices in HCI, which, as understood by Pierce et al. [104], comprise areas such as research through design [44, 140], speculative design [34], ludic design [48], reflective design [113], and design fiction [14], among others [27, 53, 60, 103]. The intersection of these disciplines is their interest in designing for alternatives, for unknown futures, and for a critical reflection on the societal and technological status quo. Thus, the best differentiation to non-speculative ideas, concepts, or artifacts lies in the opposing position to the otherwise "utility-oriented, feature-laden, and productivity-enhancing development of digital technologies" [58]. Therefore, the adjective "speculative" is used to describe the purpose and intent of the related research – imagining alternative interfaces and interactions. Whereas, Research through Design (RtD) – as an umbrella term – specifies the process to pursue this intention in an exploratory manner.

Under the umbrella term of **Real-World Patterns** (RWP), I understand two fundamental concepts of design used in HCI. First, the idea that instances of technology can create intelligibility by referencing a familiar gestalt in their design. Therefore, this can be thought of as a pattern of matter as it occupies or originates from the physical space of the lifeworld. Second, the humans' internal representation of such concepts and ideas, which can be conceived as a pattern of thought. These patterns of thoughts include, among others, mental models, internalized processes as well as social norms, behavioral patterns, cultural practice, and conventions. Both types of patterns (of matter or thought) are inseparable in Lokoff's and Johnson's [82] understanding of the metaphor since "meaning is grounded in bodily experience [... and] that any abstract concept can be shown to depend on mental images" [13].

[1] www.alandix.com/academic/papers/theory-formal-2003/glossary.html

Despite its apparent similarity to the concepts of metaphors, I consciously use the term RWP since metaphors are only one possible expression of this relation between thought and matter which humans use to conceptualize the world. Therefore, I adapt the concept of the *similarity space* (described in Chapter 3.1.4) from the cognitive sciences as used by Gentner [49] in her work about structure mapping to provide a more detailed differentiation of the metaphor term to describe the transfer and interrelation between a concept and an artifactual instance.

The perspective provided by the similarity space helps to draw the picture, how the purposeful and conscious use of RWPs in the transfer into speculative artifacts addresses central RtD purposes. When referring to RtD purposes, I draw from Höök et al. [65] who, based on Mazé and Redström [88], specified these purposes to be of “generative, evaluative, inspirational, descriptive, [or] critical” [65] nature.

1.3 Overview

To exemplify this approach of using RWPs to inform HCI, I follow the form of annotated portfolios as proposed and discussed by Gaver [47], Bowers [19], and Löwgren [85] as a way to document and contextualize the conducted work presented in this cumulative doctoral thesis. Further, the annotation provides additional perspectives that help to ground future work and to guide and inspire researchers and practitioners. The thesis is structured as follows:

- Overview on the selected artifacts.
- Establishment of the annotation themes.
- Expression of the selected themes in the artifacts.
- Discussion of the presented work in the context of current HCI topics and research.

The annotation themes elaborate on the following three guiding questions (**Q1**-**Q3**) which are concerned with the usage of RWPs in the process of designing HCI interfaces. Since the focus of the work lies in designing speculative artifacts, meaning imaginative and critical research objects, the questions reflect on the application of RWPs in the RtD process – as a collective term for research practices directed towards exploratory practice.

Guiding Questions

Q1 How does the use of RWPs in the design of speculative artifacts **complement RtD**?

Q2 How can RWPs be consciously **instrumentalized in the design** of interfaces?

Q3 How is the human-technology **relation affected** due to the use of RWPs?

On a general level, the included projects rely on RWPs in the design and research process as (1) a resource for generating ideas and concepts, (2) a method to put humans in a comprehensible confrontation with artifactual speculations, and (3) a source for inspiring new research questions and design ideas. The projects further demonstrate how the patterns are transferred to the artifact in the form of four similarity facets (literal similarity, mere appearance, analogy, anomaly) during design. Consequently, the resulting influence on the human-technology relation is conceptualized with the help of the postphenomenological perspective.

Applying this approach is considered to be programmatic, as it uses the same source of reference and inspiration – Real-World Patterns – exclusively and systematically in the ideation process, interface design, and experience conceptualization. This approach was applied in different HCI research domains such as in the realm of Tangible User Interfaces (TUI), Interfaces for Musical Expression, Human-Drone Interaction, Human-Robot Interaction, and feedback systems for Virtual Reality (VR) experiences. Further, the projects cover various HCI topics such as new interface materials and material experiences (see Chapter 2.1.1) as well as interaction concepts for involving, social, and intelligent technologies (see Chapter 2.1.2). The speculative nature of the artifacts refers to their orientation towards alternative interface and interaction concepts and their exploratory and critical impulse instead of a user-requirement-oriented motivation.

In that manner, the contribution of the work included in this cumulative thesis to the field of HCI is allocated to contributions via:

1. The eight **speculative artifacts** presented, which exemplify the integration of RWPs from social norms, human behavior, cultural practice, and from the natural world into concrete interactive technologies.
2. The **theories and concepts** developed in the design process inspired by the used RWPs, including representation of interface functionality via shape, using irreversibility to stimulate reflective engagement with technologies, and creating comprehensibility through cultural or material inherent patterns.
3. The **empirical knowledge** deduced from studies and surveys in the context of the artifacts and theories. These include among others, humans' attitude towards robot punishment, or the influence of social touch on perceived agency.
4. The **analysis and reflection** of the programmatic approach through the complementation of the RtD process, understanding facets of transfer from RWP to artifacts, and the impact on the human-technology relation.

2
CONTAINED ARTIFACTS & CONCEPTS

... as if research always involves going over old territory, while art, craft and design are of course concerned with the new.

– Christopher Frayling [44]

This Chapter provides an overview of the projects that form the main body of this thesis before annotating the projects concerning questions **Q1-Q3** introduced earlier. Therefore, I briefly present their outline, describe the speculative artifacts, as well as the associated concepts. An overview is compiled in Table 2.1, which contains a short project description (RWP highlighted in bold) and references to the publications. The individual contribution types are indicated regarding three categories [135]: Artifact, Theoretical, and Empirical Contribution. The individual weights classify the contribution in relation to the topic of this thesis and are not intended as a general classification.

	Project	A	T	E	RWP	Ref.
New Materialities	**StringTouch**	●	●	•	An exploration of **string instruments** to inform new interface morphologies.	[P5]
	COMB	●	●	•	An interface which considers shapes as used in **constructive play** to define functionality.	[P9]
	TouchGrid	●	●	•	An interface concept for combining benefits of grid interfaces with advantages of the ubiquitous **touch interaction patterns**.	[P11] [P10] [P7]
	Traces of Use	•	●	•	An investigation of **wear and tear** to indicate interfaces on urban materials and buildings.	[P1] [P2]
	Undesigning Undo	●	●		An investigation of the potential use of **irreversibility** in interface design.	[P6]
Artificial Sociabilities	**Punishable AI**	•	●	●	A speculative concept of human robot interaction based on **physical punishment** and the exploratory investigation of the user response.	[P8]
	Lure the Drones		●		A concept for interacting with swarms of drones, with **falconry** as inspiration.	[P4]
	Human Touch	•		●	An exploration of the influence of simulated **social touch** during VR experiences on the perceived agency by the users.	[P3]

Contribution types based on Wobbrock and Kientz [135]: **A**rtifact, **T**heoretical, **E**mpirical Research.

● = primary contribution; • = secondary contribution.

Table 2.1: Overview of the eight projects and their contributions presented in this thesis.

2.1 Project Descriptions

The following projects contain speculative artifacts besides their empirical or theoretical contribution, which will be annotated and discussed in Chapter 4. The only exception to this is project **Lure the Drones** [P4] which describes such a system as a concept only. It is included to illustrate another facet of a RWP and its transfer in the design process.

The subsequent project descriptions and figures give a short introduction into the artifacts and concepts for the context of the later annotation, outline the used RWPs, and indicate the contribution of individual publications to a project when it consists of multiple publications. References to all original contributing publications with detailed information on the contributions, technical implementations, and used methodologies can be found on page 13. The paper "Undesigning Undo: Irreversible Interactions as a Design Strategy" [P6], which was under review at the time of thesis submission, is added in the appendix (see page 63).

Two main categories are used to summarize the projects; these are called: New Materialities and Artificial Sociabilities.

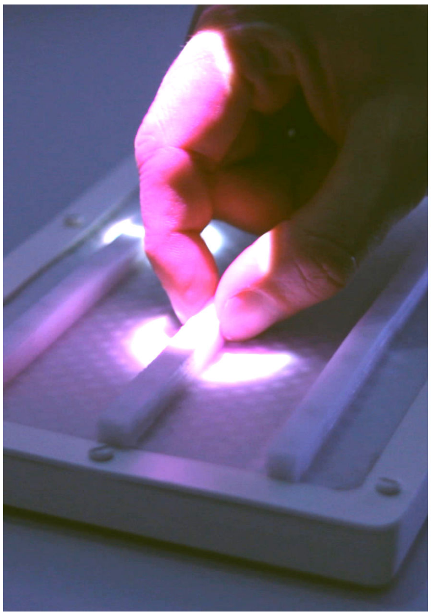
2.1.1 New Materialities

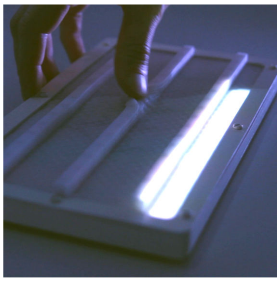
The projects [P6], [P5], [P9], [P7], and [P2] deal with the topic of **New Materialities**. The included speculative artifacts explore new types of interactive materials, material experiences, novel forms of interaction with such objects, and implications of hybrid interfaces on the human-technology relation in the intersection between touch and deformation. In that sense, this research explores what Fuchsberger et al. [45] call "the active role of media", which subsequently leads to "new ways of interaction, which nevertheless can integrate formerly used interaction techniques" [45]. Due to their object character and materiality, the presented projects fall into HCI domains such as Tangible Interaction [67, 72], Deformable [18], Shape-Changing [24], or Organic [62] User Interfaces.

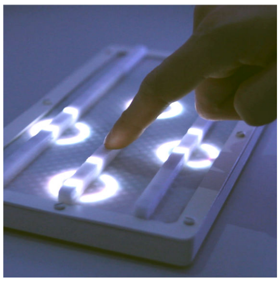
StringTouch [P5] explores the diverse culture of **string instruments**, the abstraction of therein present interaction patterns, and provides a first translation of this RWP into a speculative artifact. This exploration addresses the translation of existing design and interaction patterns into novel morphologies for interfaces using flexible materials as opposed to planar and rigid interaction surfaces found in touchscreen devices. Thus, new types of interfaces are created that address specific challenges such as circumventing the Midas touch problem and designing for actions that stay in the human periphery for on the side interactions. The project provides a theoretical and conceptual as well as empirical and artifact based examination of the topic.

In its materialization, **StringTouch** is a speculation on new forms of interactive display technologies and associated interactions, exploring the RWP of string instruments. The project

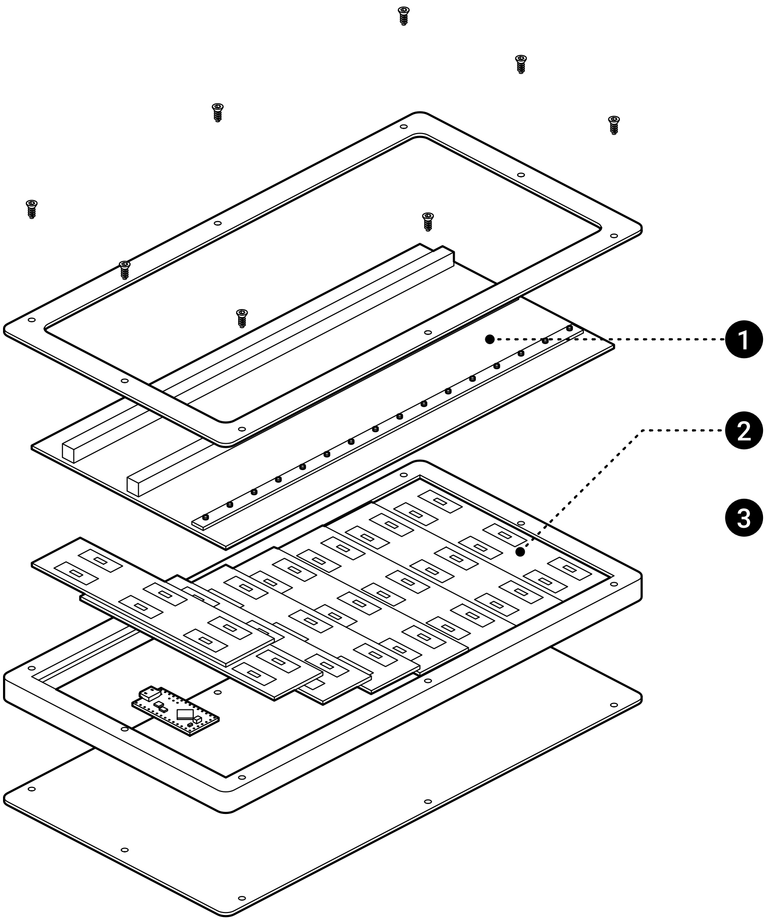
StringTouch







StringTouch investigates musical string instruments as a basis for novel interfaces. This RWP was selected since string instruments have a long cross-cultural tradition and exist in many variations that lead to multifaceted interactions. They have remained mainly unconsidered in HCI. The speculative artifact transfers the string instrument morphology into silicone ridges along the interface surface. These enable the interactions deduced from the instrument context.



The interface consists of two main layers: ❶ a flexible silicone surface with ridges that include magnets, ❷ a PCB layer with capacitive touch plates and hall sensors to track the interface's deformation.

contributes artifacts and concepts which exploit unconsidered interaction possibilities in the interface design.

COMB [P9] investigates the idea of modular and constructive TUIs that make use of the constructed shape as an input method for defining an interface's functionality. This approach stands in contrast to constructive interfaces, which define functionality as the result of operation composition as done by interfaces in the domain of tangible computing. Thereby, COMB takes into account the RWP of **constructive play** with building blocks and human capabilities of object and shape recognition. The advantages of this concept are studied in the context of learning through imitation in a musical setup.

COMB speculates about alternative concepts in the interaction with modular interfaces, using the RWP of constructive play. It contributes an artifact which is an exemplary implementation in the form of an interface for musical expression.

TouchGrid [P7] is the prototypical implementation of a musical grid interface that offers touch interaction on top of the low-resolution button matrix, besides the standard button input. It draws on established interactions familiar from ubiquitous **touch interaction** to address recurring design tasks such as navigation and menu access. Thereby, issues such as comprehensibility and the effective use of a low-res in-/output device's resources are addressed. The concept is derived from an investigation of trends in the music-making community and therein present needs [P11] and an in-depth investigation of musical grid interfaces [P10] and their common designs.

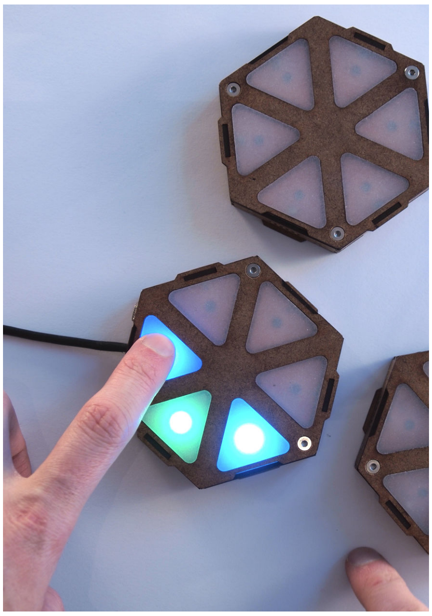
As such, **TouchGrid** speculates about hybrid interface forms combining familiar interactions from the RWP of touch interaction with the tangible properties of button matrices. The project contributes a solution to limitations present in the context of musical grid interfaces.

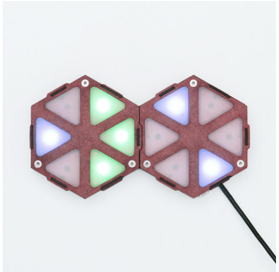
Traces of Use [P2] explores the idea of reusing traces on materials, as found on old and used objects or surfaces, to indicate patterns of interactivity [P1]. While **wear and tear** in the real world are based on years of use, this concept explores the possibility of shaping human behavior based on artificial traces – as imprints of designed behavior – to stimulate intended interactions. Thus, Traces of Use can be considered signifiers or nudges that integrate seamlessly into the everyday environment. This concept was examined theoretically and practically via the elicitation through speculative artifacts to show that humans can recognize and interpret such traces.

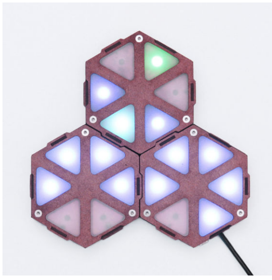
Traces of Use[1] is a speculation on unobtrusive interfaces in urban environments using the RWP of wear and tear on materials and objects. It contributes the evaluation of the concept's comprehensibility and proposes prototyping techniques for the implementation.

[1]The papers [P1, P2] are core contributions of Linda Hirsch's research and will be part of her doctoral thesis.

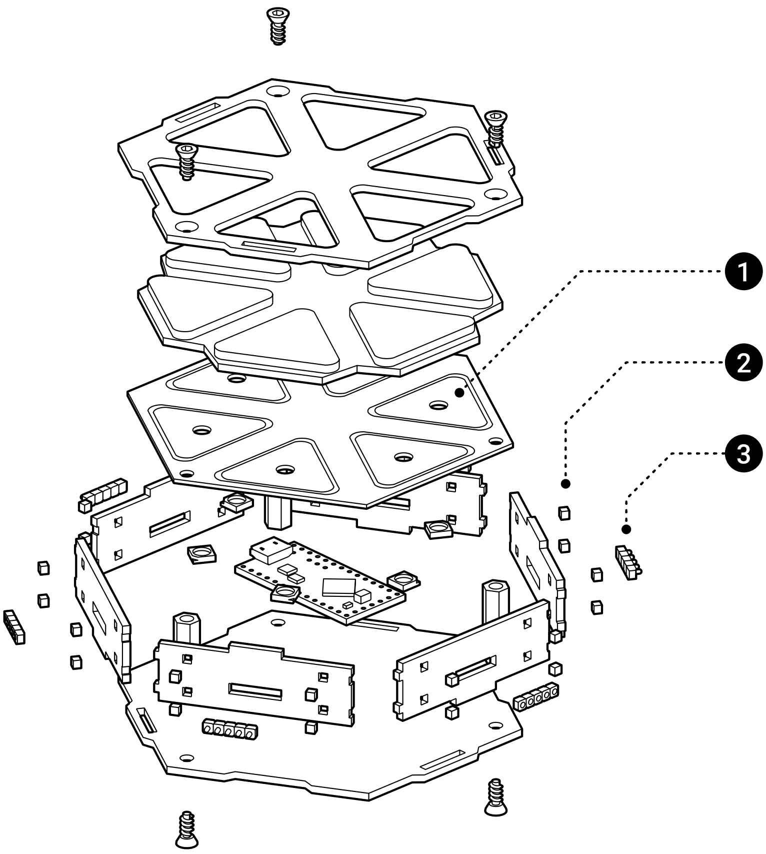
COMB







COMB is a modular interface that explores constructive processes such as playing with building blocks. The shape of the built objects is considered not as a consequence of the construction but as a meaningful representation. Thus, the modular artifacts can be rearranged in different shapes to select different functionalities. The interaction concept was easy to observe and imitate. Further, it was possible to extrapolate new interactions based on it.



❶ Capacitive plates detect the interaction with the illuminated grid cells. Each module connects via ❷ magnetic connections to other modules. ❸ Pogo pins transfer data between the modules and are used to determine the shape.

Undesigning Undo [P6] is a discussion about the concept of the material's inherent **irreversibility** in the context of interaction design and thus especially in the realm of tangible user interfaces for which materiality is an inherent component. The question is if the interaction with technology and the within implemented user freedom in the form of undo functionality contradicts the experience of causality in the real world. Three design speculations exemplify the effects of irreversibility on the experience throughout the interaction. The impact of these interactive artifacts, which incorporate irreversibility in their designs, is observed, discussed, and conceptualized.

Undesigning Undo speculates on alternative interaction paradigms, using irreversibility as a RWP. Its contribution lies in the conceptualization of irreversible interactions and their transfer into design strategies to influence awareness and reflection during interaction.

The five projects presented as **New Materialities** adapt RWPs taken from cultural objects and practice as well as from the human knowledge about the working-principles of the lifeworld. The transfer of the patterns into the speculative artifacts is executed with varying degrees of abstractness with the primary goal to explore novel and yet unconsidered interface forms and interaction patterns. The artifacts in these cases are tools to be worked with and interfaces to be used.

2.1.2 Artificial Sociabilities

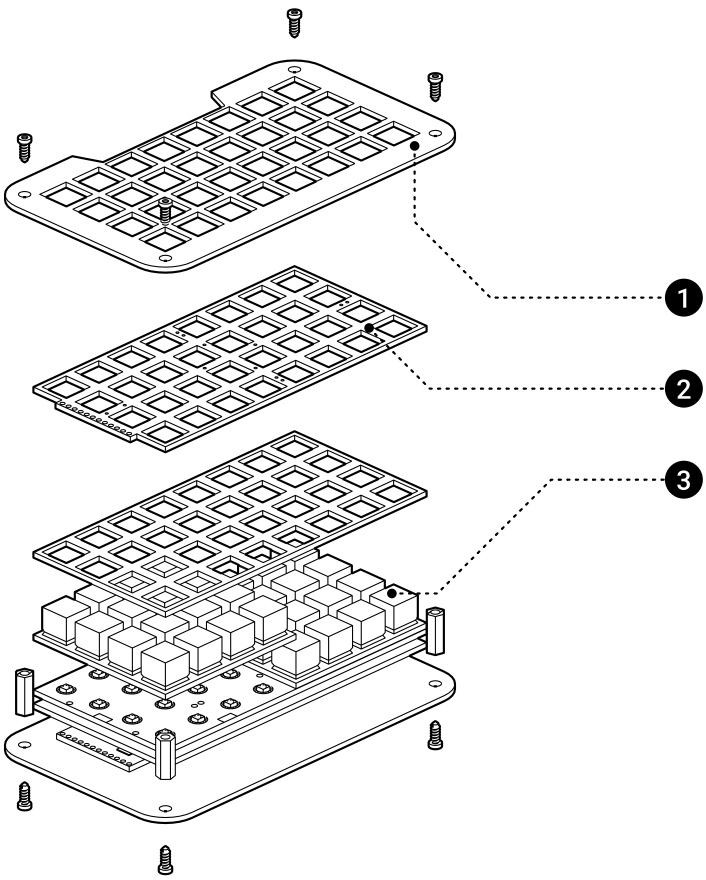
Projects [P8], [P4], and [P3] revolve around the theme of **Artificial Sociabilities** and explore the ever-changing relationship between humans and intelligent systems that leave the virtual sphere and enter the physical space of the real world – and are thus not only physically but also socially present in the human lifeworld. In that sense, the research is concerned with what is defined by Don Ihde [69] as the alterity relation – this is "not [being] related, as in mediating relations, via a technology to the world; rather, [it is being] related to or with a technology" [2]. The projects conducted span over different HCI domains and include the interaction with virtual agents in mixed reality and VR situations, self-learning robotic systems, and groups of semi-independently acting drones.

Punishable AI [P8] investigates the speculation on future interaction with self-learning machines in everyday environments and training scenarios. Via the implementation of the RWP of **punishment** as a feedback method, the human-technology relation is critically examined, and thus the predominant design trend of anthropomorphization in the interaction design of intelligent machines is questioned. The confronting nature of the study setup provokes the participants to form an opinion that is used to reflect on the design of intelligent, social, and ubiquitous machines or systems.

As such, **Punishable AI** is a speculation on the effect of anthropomorphization on human-technology relations, provoking the discourse via the RWP of physical punishment. Contributing, the reflection on and the examination of the human response due to this interaction.

TouchGrid

TouchGrid builds on the similarity of low-resolution button matrices (grids) to touchscreen interfaces. It transfers established interaction patterns from one interface domain to the other. Interactions such as swiping and drag from off-screen are used to enable navigation among applications and for accessing menu systems. Thus, the TouchGrid interface offers all original functions of a grid but is enhanced with touch interaction.



The TouchGrid artifact uses a ❸ commercially available grid kit and adds an additional ❷ PCB layer with capacitive touch plates. This layer seamlessly merges with the ❶ normal enclosure of the interface.

Lure the Drones [P4] explores and proposes new interactions patterns in the interaction with groups of drones as a theoretical and conceptual exploration. As a parallel to the real world, the idea is pursued that flying drones share characteristics and properties with birds and that thus interaction patterns from **falconry** could be used as a basis for human drone interaction concepts. This transfer includes aspects such as body posture in the context of giving commands to the birds and interacting directly within the world without any manifest technological layers dividing the human and the flying agent.

Lure the Drones speculates on alternative relations to flying agents using the RWP of falconry to enhance the situatedness of humans during the interaction with drones. It contributes a conceptual exploration and transfer of falconry into a human drone interaction concept.

Human Touch [P3] explores the capabilities of recreating real-world bodily experiences to influence a human's perception of virtual characters. Via the physically mediated touch of an artificial hand, the boundaries between human and computer-controlled characters are blurred. In addition to exploiting the haptic quality of feedback, the essential perspective of the project is the inherent social component of the interaction, referred to as **social touch**.

Human Touch[2] speculates on a method to increase the perception and acceptance of entities in virtual realities, using the RWP of social touch. This project contributes an evaluated method to increase the agency of non-human actors in VR.

The three projects presented as **Artificial Sociabilities** demonstrate RWPs adapted from social norms and behavior patterns, which overlap with patterns from cultural practice. In the design of their speculative artifacts, they rely on a naturalistic ad literal transfer of the RWP into objects and systems.

How the use of RWPs complements RtD (**Q1**), how the individual projects transfer RWP into artifact design (**Q2**), and how the human-technology relation is subsequently affected (**Q3**) is going to be discussed and disclosed in the individual annotation sections in Chapter 4.

[2]The paper [P3] is a core contribution of Matthias Hoppe's research topic and will be part of his doctoral thesis.

[P1] Hirsch, L., Rossmy, B., Bemmann, F., and Butz, A. "Affordances Based on Traces of Use in Urban Environments." In: *Proceedings of the Fourteenth International Conference on Tangible, Embedded, and Embodied Interaction*. TEI '20. Association for Computing Machinery, 2020, pp. 729–742. DOI: `10.1145/3374920.3375007`.

[P2] Hirsch, L., Rossmy, B., and Butz, A. "Shaping Concrete for Interaction." In: *Proceedings of the Fifteenth International Conference on Tangible, Embedded, and Embodied Interaction*. TEI '21. Association for Computing Machinery, 2021. DOI: `10.1145/3430524.3440625`.

[P3] Hoppe, M., Rossmy, B., Neumann, D. P., Streuber, S., Schmidt, A., and Machulla, T.-K. "A Human Touch: Social Touch Increases the Perceived Human-Likeness of Agents in Virtual Reality." In: *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. CHI '20. Association for Computing Machinery, 2020, pp. 1–11. DOI: `10.1145/3313831.3376719`.

[P4] Rossmy, B. and Holländer, K. "Lure the Drones - Falconry Inspired HDI." In: *1st International Workshop on Human-Drone Interaction*. iHDI '19. Ecole Nationale de l'Aviation Civile [ENAC], 2019. `https://hal.archives-ouvertes.fr/hal-02128393`.

[P5] Rossmy, B., Rümelin, S., and Wiethoff, A. "StringTouch - From String Instruments towards New Interface Morphologies." In: *Proceedings of the Fifteenth International Conference on Tangible, Embedded, and Embodied Interaction*. TEI '21. Association for Computing Machinery, 2021. DOI: `10.1145/3430524.3440628`.

[P6] Rossmy, B., Terzimehić, N., Buschek, D., Döring, T., and Wiethoff, A. "Undesigning Undo: Irreversible Interactions as a Design Strategy." In: *Proceedings of the Sixteenth International Conference on Tangible, Embedded, and Embodied Interaction*. TEI '22. Association for Computing Machinery, **SUBMITTED**.

[P7] Rossmy, B., Unger, S., and Wiethoff, A. "TouchGrid – Combining Touch Interaction with Musical Grid Interfaces." In: *Proceedings of the International Conference on New Interfaces for Musical Expression*. NIME '21. 29, 2021. DOI: `10.21428/92fbeb44.303223db`.

[P8] Rossmy, B., Völkel, S. T., Naphausen, E., Kimm, P., Wiethoff, A., and Muxel, A. "Punishable AI: Examining Users' Attitude Towards Robot Punishment." In: *Proceedings of the 2020 ACM Designing Interactive Systems Conference*. DIS '20. Association for Computing Machinery, 2020, pp. 179–191. DOI: `10.1145/3357236.3395542`.

[P9] Rossmy, B. and Wiethoff, A. "COMB – Shape as a Meaningful Element of Interaction." In: *Proceedings of the Thirteenth International Conference on Tangible, Embedded, and Embodied Interaction*. TEI '19. Association for Computing Machinery, 2019, pp. 287–295. DOI: `10.1145/3294109.3295646`.

[P10] Rossmy, B. and Wiethoff, A. "Musical Grid Interfaces: Past, Present, and Future Directions." In: *Proceedings of the International Conference on New Interfaces for Musical Expression*. NIME '21. 29, 2021. DOI: `10.21428/92fbeb44.6a2451e6`.

[P11] Rossmy, B. and Wiethoff, A. "The Modular Backward Evolution — Why to Use Outdated Technologies." In: *Proceedings of the International Conference on New Interfaces for Musical Expression*. NIME '19. 2019, pp. 343–348. DOI: `10.5281/zenodo.3672988`.

3

BACKGROUND & ANNOTATION THEMES

To understand how RWPs are used to inform interfaces, systems, or concepts, the historical development of the HCI practice has to be considered to reveal current research topics, trends, and purposes. In this chapter, I will provide the theoretical context regarding the guiding questions **Q1**-**Q3**. Therefore, I will set forth the necessary background to understand:

(1) How research objectives, knowledge production, and research purposes changed as HCI evolved as a domain. This aspect is going to be the basis to reflect on how RWPs can complement research purposes and can be utilized in the RtD process (**Q1**).

(2) How references to the real world have been used to create intelligible interfaces and interactions and further how such "analogical" design relates to concepts from the cognitive sciences. This grounding will facilitate a detailed comparison on how to transfer, translate and instrumentalize RWPs in the artifact design (**Q2**).

(3) How technology design influences human-technology relations and thus how consciously chosen RWPs can shape these relations. Understanding this influence is from interest for a postphenomenological contemplation of the speculative artifacts (**Q3**).

3.1 Background

3.1.1 Waves of HCI Research

Theorists divide the work done in HCI through the late 2010s into three waves, commonly referred to as the three waves of HCI [31]. Each wave evolved as computers became established in professional, personal, and social life, which changed the research topics, issues, and challenges. Put simply, the use of computers turned from (1) person – computer, (2) group – computer, to (3) society – computers, thus changing the conceptualization of the "human-computer" system in its entirety. Following Bødker [17] and Harrison et al. [56], first-wave HCI emanates from human factors research that seeks to improve human-machine coupling. The second wave, influenced by cognitive sciences, focused on well-defined practices and communities and the therein present information processes. In third-wave HCI, computers eventually dissolve into the real world with all its challenges, inconsistencies, and diversities [43]; thus, third-wave HCI spotlights topics such as culture, values, and ethics [31]. Although the three waves emerged sequentially, they continue to exist in parallel because their research foci do not replace each other.

As a result, HCI research goals expanded, as did the classification of what constituted "good" design. First- and second-wave, with a focus on individuals' performance, interaction context, and collaboration, evaluate systems based on metrics such as being “effective, efficient, engaging, error-tolerant, and easy to learn” [38]. Whereas the third-wave shifts to an appreciation of softer qualities such as the emotional and experiential properties of interaction and is interested in lessons about the integration into society and consequent cultural implications [17]. These developments further influenced how research practice itself is understood and triggered a reflection on the impact of art [7], design [15, 78], and social sciences [8] on the HCI domain [65].

3.1.2 RtD purposes in the HCI Research Practice

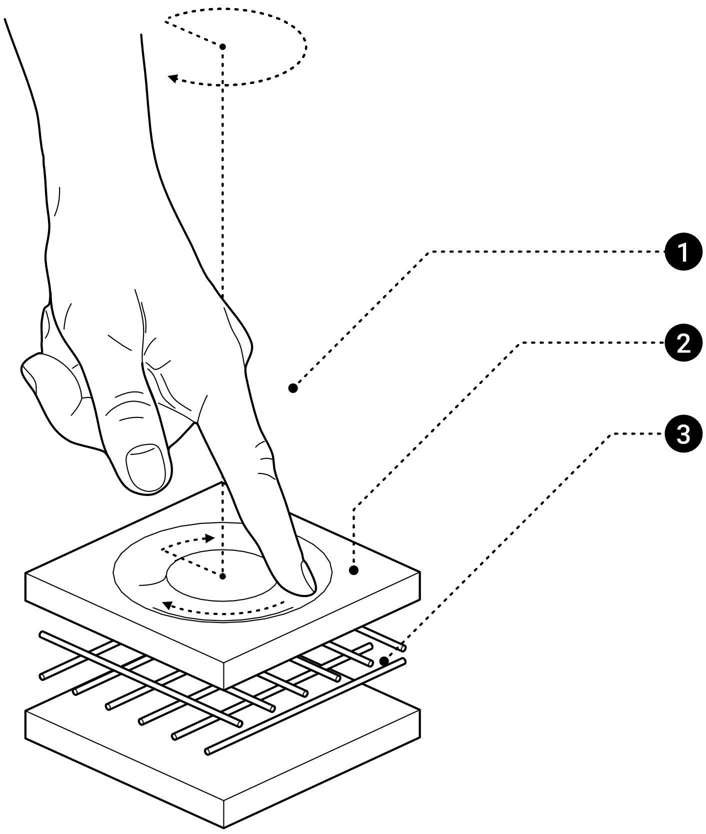
Within the HCI community, the research projects conducted on this intersection of domains are often generalized as Research through Design (RtD) [44] approaches. While this does not differentiate methods and contributing domains, the umbrella term is sufficient for this work to specify exploratory design processes and research focused on intermediary knowledge production [64, 65, 66]. It needs to be emphasized that design research is not about giving a research artifact its “design”, i.e., its external appearance, but about creating knowledge through the act of designing [139]. By engaging in the design practice, artifacts are created which are “intended to be carefully crafted questions” [139]. Within that, RtD can speculate about upcoming futures [130], can enhance ethico-political discussions [43, 79], or act critically “to the extents that it proposes a perspective-changing holistic account of a given phenomenon” [6].

So instead of providing generalizable answers, RtD strives to find new questions. Instead of determining a system’s optimal structure, RtD generates and inspires structures. As Dunne and Gaver [33] put it for speculative design: “The aim is not to assess the design’s usability [...], the purpose is to trigger people’s imaginations, to challenge them to consider how [...] technology might fit into their lives”. As a result, HCI can act as a “lens through which to understand being human in a changing world” [12].

The design of speculative artifacts as a RtD method provides the potential to engage with future developments, to experience, discuss, and reflect on the design of technology and thus the “crafting of research products allows [...] to investigate human-technology-world relations and technological mediations by not only studying them but also taking part in creating them” [58]. As a result, RtD often shifts from being user-centered to being based on the designers’ authorial voice [110], which can serve criticality, innovation, and disruption [104] since the designers take a “personal role in the process” [86]. This shift does not displace the users but transforms their role as potential consumers into “collaborators in discovering new meanings” [104].

Traces of Use

Traces of Use imitates usage patterns on materials and surfaces to indicate interactive areas of user interfaces. Since humans are able to perceive traces and interpret the preceding actions, Traces of Use can be considered artificially created signifiers to stimulate intended human behavior. Due to the used materials and the design language, Traces of Use embed unobtrusively into urban environments. Material changes such as discoloration, aging of the surface finish, or material abrasion are replicated to create specific affordances.



Traces of Use can be included in typical construction materials such as ❷ concrete surfaces. In that case, ❸ the internal metal mesh can function as a capacitive grid to track ❶ user interaction.

3.1.3 Of Analogical Design and Interface Metaphors

When technologies aim to be used without instructions conveyed by user manuals, they strive for designs that are comprehensible [116], self-revealing [61], self-explaining [23], intuitive [5], or natural [46] in use. Different strategies, such as replacing abstractness with direct manipulation [116], using metaphors built on human's prior knowledge [91], or directly transferring objects' appearance to the screen (skeuomorphic designs) [52, 94, 124], all have in common that they try to eliminate or at least reduce this need for instruction.

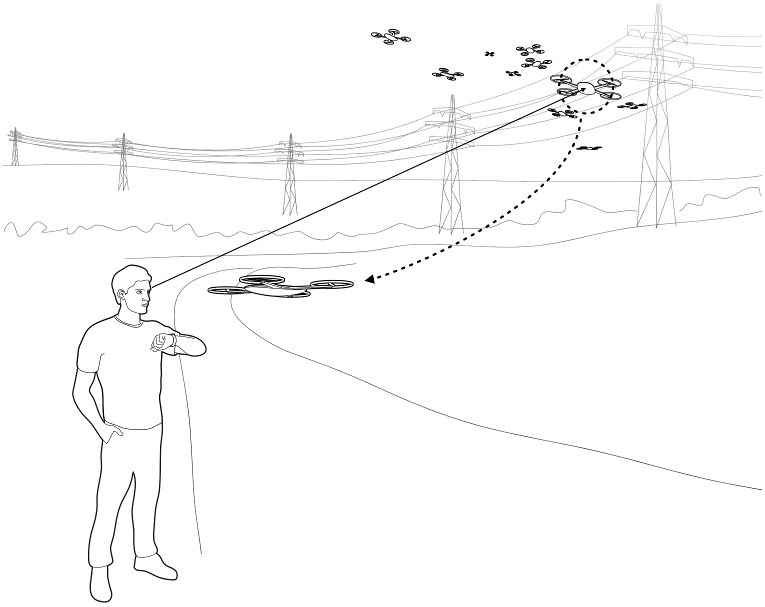
When leaving the virtual and entering the physical realm, the objects' properties – the so-called perceived affordances – offer particular interaction possibilities. Following Norman [93], designing with affordances is about "If the desired controls can be perceived" and "If the desired actions can be discovered" based on the physicality of an artifact. Still, interfaces such as Tangible [72, 114], Organic [63], or Shape-Changing User interfaces [81] include an explicit design component. Just like interface metaphors, physical artifacts use references to the real world [118] to create comprehensible interactions. E.g., tabletop interfaces [100] use physical items as abstract containers for virtual information [115] to enable physical interaction with data [25, 77], familiar real-world objects [71] are used as vehicles to trigger human conceptual understanding, or the replication of known human-like behavior patterns makes technology comprehensible and expressive through an inherent familiarity [54, 68]. This blending of technology and the lifeworld, as intended by ubiquitous computing [132] and tangible interaction [73], leads to technologies that are embedded in the real world, take inspiration from the real world, but as well make use of humans' familiarity with the real world, creating "Interactions like the Real World" [74].

Hence, the humans' reality serves as a blueprint for a comprehensible interaction design. While this is often referred to simply as the use of metaphors in interface design – which means "understanding and experiencing one kind of thing in terms of another" [91] – it is more about a consciously constructed **similarity** between the conceptual understanding and the factual instance.

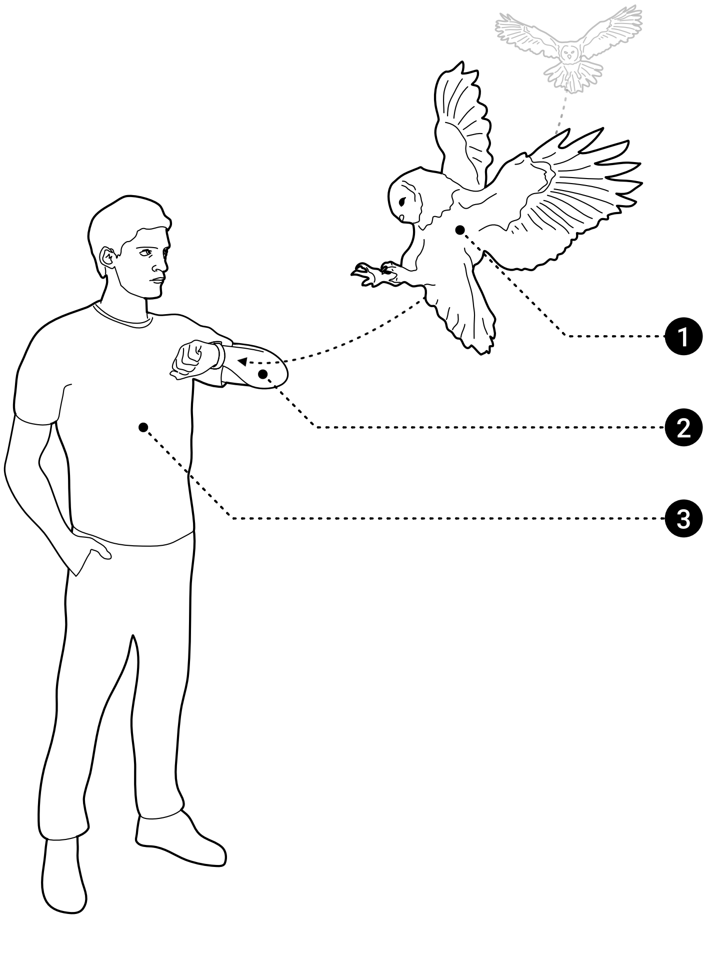
3.1.4 Of Analogical Reasoning and the Similarity Space

As mentioned earlier, using references to the real world provides a basis for understanding an artifact and the associated interactions. Such references can be described as analogical, insofar as analogies refer to "a comparison between two objects, or systems of objects, that highlights respects in which they are thought to be similar" [10]. Considering what cognitive scientists understand as analogical reasoning [80] can help to conceptualize the different facets of such references. As conceptualized by Gentner in her work on *Structure Mapping* [87], these references are about shared properties and relations between the source and target domains. Similar to the hermeneutic principle of "Heidegger's ontological analysis of Dasein, human understanding is always interpretive (we always understand something 'as-something'), which means that interpretation is an inescapable part of being-in-the-world" [1].

Lure the Drones



Lure the Drones transfers the interaction between falconers and their birds to the domain of human drone interaction. This concept explores a direct and in the real world situated interaction with these flying agents instead of indirect and distant interactions via remote controls or computer applications. Interactions take place via signals in the form of body posture, gaze, and hand gestures.



The interaction between ❸ falconer and ❶ bird are transferred analogically to the use case of human drone interaction. The falconer's body posture becomes a symbol for the intended command – ❷ a call back home.

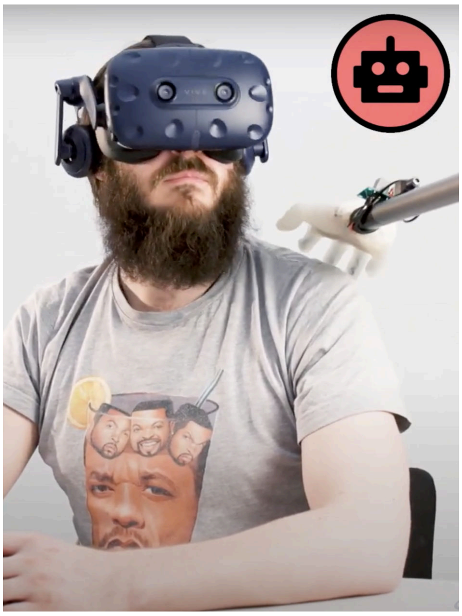
Following this, analogies, metaphors, mere appearance, anomalies, or literal similarities are all just facets of references resulting in the so-called **similarity space** [49] (cf. Figure 4.4), which allocates the shared properties and relations of such references. Applying this differentiation to interface design shows that referencing reality to imply interactions does not consequently lead to interface metaphors. Furthermore, since in Gentner's understanding metaphor lies vaguely between the other four, easily distinguishable, edge cases, it is excluded for further classification. Different design approaches can be allocated to the remaining four subareas of the similarity space. The following HCI projects exemplify this in more detail.

Taken from the previous example, using a bottle [71] as a representation for a data container can be thought of as using **Analogy** in its design. Here, the bottle does not actually store the information but instead functions as the interface to manipulate the data. Hence, it offers associations from prior experience such as open to access, pour to empty, or shake to reorder. Mapped to the similarity space, this design shares many relations but no to only a few attributes. Other designs explore new types and forms of interfaces by literally copy the real-world model to the technological context. Examples are interfaces that use ropes to steer virtual kites [138], kinking wires to control the flow of electricity or data [112], or recreate anthropomorphic appearance and behavior to enable interaction with computer systems [20, 120, 121, 122]. By doing that, a **Literal Similarity** is created, sharing many relations and attributes between the real-world model and the technological artifact. Opposing the Analogy, the **Mere Appearance** shares primarily attributes and quasi no relations. In the example of *PianoText* [41], the keyboard as the main interface of the piano is directly and unaltered used in a different context. Playing the keys is used for text input and allows to enter letters or whole words by performing a sequence of notes or chords. Even the transfer of other expressive elements of the piano play, such as the key velocity, is conceivable to "differ between capital and lower case letters" [41]. In the final quadrant of the space, we find the **Anomaly**, which is easiest to understand by imagining what it is not. Anomalies in the design can be characterized as not being similar and subverting expectations. Here, the domain of counterfunctional [103] and counterfactual [130] design provides a broad palette of examples. In the words of Hauser, an object of this type "intentionally contradicts what would normally be considered logical to create given the norms of design and design products" [58]. This perception is evident in works such as *Tilting Bowl* [131] or *table-non-table* [59], both of which exhibit behavior through periodic motion that is not common to the original objects the artifacts are modeled on, and which therefore breaks with human assumptions and disrupts usage intentions.

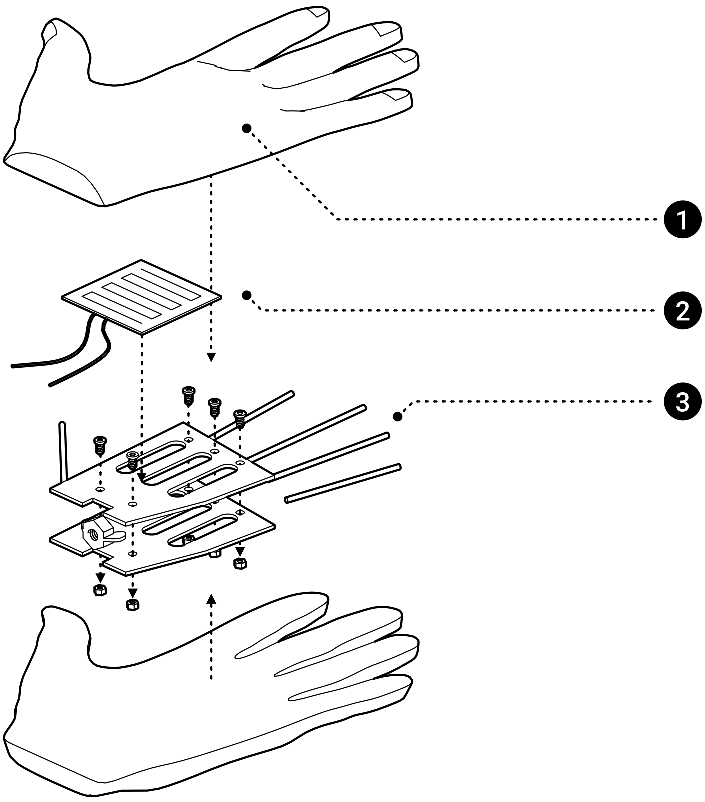
3.1.5 The Postphenomenological Perspective in HCI

The techno philosophical perspective of postphenomenology was developed over the last decades to understand and conceptualize the social and cultural roles and influences technology – and the design of technology – has in the human lifeworld. Postphenomenological studies generally focus on investigating "technology in terms of the *relations between human*

Human Touch



Human Touch explores the element of social touch in the context of virtual reality experiences. Such as small social interactions convey more meaning in everyday situations than superficially encoded; social touch in VR influences the perception of characters and their agency for the experiencing human. Therefore, a silicone hand was built that replicates a human hand with anatomical correctness.



Inside the ❶ silicone hand is a simple ❸ wire skeleton and base construction that helps posturing the hand and provides a realistic stiffness. Further, an ❷ electric heating pad heats the hand up to body temperature.

beings and technological artifacts" [108]. These relations are understood either as relations through technology in a mediating function between the human and the lifeworld or as relations of humans with technology itself [1]. As such, Don Ihde [69] (cf. Figure 4.5) originally defined four human-technology relations, which are as follows: embodiment, hermeneutic, alterity, and background relations. These relations describe to which degree technology is involved and perceivable in an interaction. Classic exemplary technologies for these relations are (1) glasses which are "embodied", i.e. that interaction with the world takes place through them without being noticed; (2) a thermometer through which the world is "hermeneutically" interpreted; (3) a vending machine which is something other within its system ("alterity"); and (4) technologies such as air conditioning which work in the "background" not involved in a mediating function. These categories have been expanded with other relations, as new research topics, such as virtual and augmented reality (augmentation and immersion [125]) and body integrated systems and interfaces (cyborg relation [109, 126]), have been added to the HCI agenda. However, the main four categories are sufficient in the context of physical artifacts and technologies involved in HCI. Such an understanding of technology is essential since it discloses how technology influences human relations to their typical lifeworld through technology or because of technology. As added by Verbeek [127] these relations can further be conceptualized regarding two essential perspectives. In his opinion, such relations influence properties of *experience* and *existence* in the interaction. These perspectives are concerned with the perception and interpretation (experience) and the action and involvement (existence), as such technology either transforms, i.e., amplifies or reduces (experience), or translates, i.e., invites or inhibits (existence). This understanding is essential to "describe and analyze technologies in a rich and consistent way" [97]. Postphenomenology used as a tool to understand, analyze and classify technological systems has recently become established in HCI research [29, 59, 76, 106, 131] and even the other way around, creating research products can be considered applied postphenomenology [58].

3.2 Annotation Themes

As described in the previous sections, HCI has undergone significant developments since its inception. From a discipline that originated from engineering and computer science, it has evolved into an interdisciplinary interwoven field that brings together researchers and research interests from the social sciences, the arts, design, and philosophy. In light of these developments, I will present my work on utilizing RWPs in crafting speculative artifacts as design probes or exploratory experiences – simply as manifestations of speculations – regarding future technologies or challenges. Therefore I will annotate the presented portfolio of research work with the following three themes that ask how RWPs can be utilized to complement the RtD practice (**Q1**), in the process of designing the artifact (**Q2**), and how this by implication affects the human-technology relation (**Q3**).

In doing so, I will outline in **T1** how RWPs are used in the design process of speculative artifacts and the research practice conducted, i.e., how they are integrated with and benefit different RtD purposes. This annotation illustrates how RWPs complement (1) generative, (2) confrontational, and (3) inspirational purposes of the RtD process.

Further, I will describe in **T2** how the presented speculative artifacts utilize the different subareas of the similarity space when referencing the real world to create specific associations, contexts, or experiences for the interacting human. This annotation exemplifies the transfer executed during the design process, taking the similar aspects of the RWP and selectively bringing them to the artifactual instance. This transfer exploits the similarity space in using (1) Literal Similarity, (2) Mere Appearance, (3) Analogy, or (4) Anomaly.

Lastly, I will annotate in **T3** how the presented projects can be interpreted as a materialization of postphenomenological explorations on human-technology relations and how RWPs shape these relations. Understanding this influence enables the conscious design of (1) existential and (2) experiential characteristics of speculative technologies, which is essential for the knowledge production through a confrontational engagement to transgress into the reflective territory aimed for by RtD.

Annotation Themes

T1: Complementing RtD Purposes What Research through Design (RtD) purposes are complemented through the use of RWPs in the design of speculative artifacts?

T2: Making Use of Similarity Facets In what different ways can RWPs be transferred to and instrumentalized in the design of speculative artifactual technologies?

T3: Shaping Human-Technology Relation How is the human-technology relation affected in the interaction with speculative artifacts that utilize RWPs in their design?

4
ANNOTATION

4.1 Complementing RtD Purposes

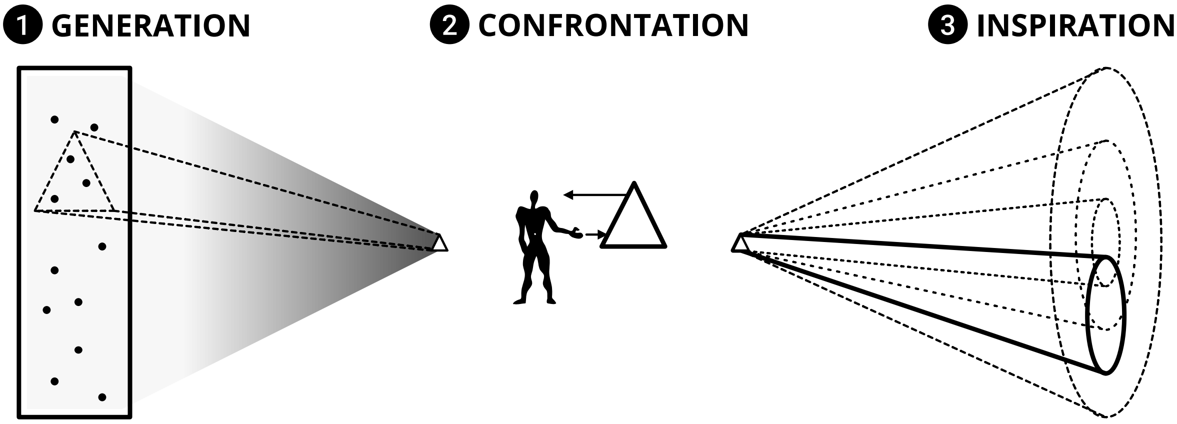


Figure 4.1: RWPs can be utilized in the RtD process to ❶ generate designs and concepts of speculative artifacts, deducing interactions or morphologies, ❷ create knowledge through the direct confrontation of human and possible future technologies or ❸ inspire new research questions and designs through experiencing the interaction with the artifact.

Besides evaluating systems based on quantifiable measures, RtD can create "generative, evaluative, inspirational, descriptive, [or] critical" [65] knowledge. As such, speculative artifacts can use RWPs in their design to complement these purposes. In annotating the included projects, I will therefore use three categories derived from these knowledge types to classify such uses of RWPs: (1) **generative**, which means that RWPs are used as resources to create designs based on such references; (2) **inspirational**, that is, trigger new ideas, concepts, designs, or questions stimulated by the use and exploration of an implemented RWP; (3) **confrontational**, which means that the RWP and affiliated associations act as a counter-design, through the experience of these an expanded understanding of technology is derived.

For this annotation, evaluative and descriptive purposes are not explicitly considered since the system evaluation is non-exclusive to the RtD approach or the usage of RWPs and are an integral part of the presented projects. Further, the descriptive purposes mentioned are considered the scientific medium to convey the insights and learnings from the individual experiments or explorations. The remaining three purposes are seen sufficient to classify the central aspects depicted by this work centered around the use of RWPs in the interface design. In the following, I will explain how the different projects are reflected within the three named purposes.

RWPs used generatively

When designers enter the design process, they must decide on a starting point to explore and deepen conceptual development. To detach themselves from common influences, existing technologies, or obvious design solutions, RWPs can be used as a programmatic approach to engage with novel ideas by asking: ”Are there comparable technologies, tools, or processes that share aspects with the problem being solved?”. This step refocuses the approach by not primarily focusing on implementation and realization but rather looking for influences that can contribute to understanding the problem. This action is followed by exploring the found references, translating the derived knowledge into design concepts, and finally, into speculative artifacts that can be experienced and investigated.

For example, the operation touchscreens in cars requires a high level of visual attention, which can be associated with safety issues. When analyzing this usage situation to generate alternative concepts, parallels to the interaction with string instruments emerged. Both are operated with the focus on the context ahead, i.e., the road with its upcoming conditions and the sheet of music with the notes to be played. And the operation is not dependent on visual attention, as it is experienced through haptic sensations. The research into interactions and design principles of string instruments led to morphologies and interaction vocabularies that revealed opportunities to approach the original problems. Interestingly, as in the case of **StringTouch** [P5], this can lead to applications in other use cases besides the original problem domain since the created abstract knowledge is generally applicable in the design context.

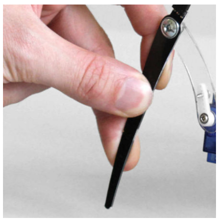
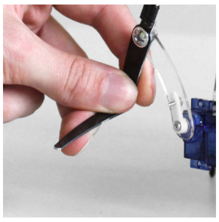
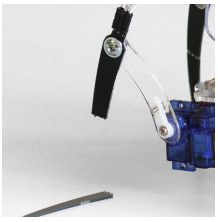
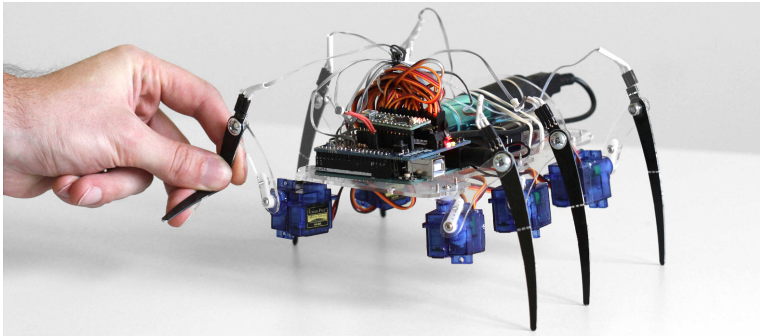
In another case, the abstract question of how novel eye-tracking technology capable of tracking gaze beyond screen boundaries could be used in the HCI context was the starting point for design explorations. The evaluation of conceivable experimental setups showed that looking at and over a smartwatch adjusts the body posture similar to a falconer luring back a bird and offering the arm for landing (cf. Fig. 3.2). In drawing this parallel, the concept of **Lure the Drones** [P4] explored this RWP of ancient human flying-agent interaction, which inspired the translation into the modern scenario of human-drone interaction.

While the prior examples referred to RWPs from human culture, RWPs can also be of modern and technological nature if they are an integral part of the lifeworld. For example, there are issues and challenges associated with low-resolution lighting interfaces [P10] that are similar to those being solved in the context of touchscreens. These include usability issues such as navigating apps and menus as well as not blocking the limited screen area with irregularly used elements. Therefore, touch interactions initially developed for high-resolution devices were adapted to low-resolution grid interfaces [92] while keeping the original and advantageous properties of the hardware controller. Due to this investigation, the **TouchGrid** [P7] was created, which is a hybrid of a classical grid controller with added touch capabilities.

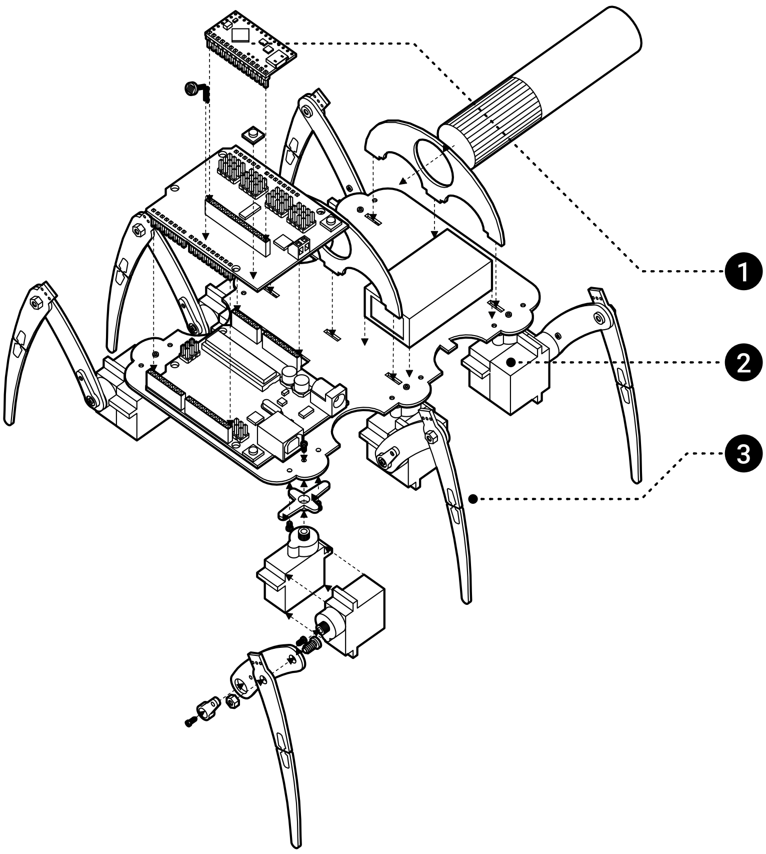
RWPs used confrontational

The previous examples have shown how RWPs can be used to start the RtD process. However, when using RWPs in the generation of concepts it can occur that the source RWP subtly

Punishable AI

The Punishable AI robot was trained via three punishment techniques in a training scenario. After scolding and dazzling the robot, its legs were broken after an unsuccessful performance. The permanent damage caused was significant and meaningful to the interacting humans. However, this method stood in contrast to participants' social values and moral principles and stimulated a reflection about the anthropomorphization of technologies. The robot's technical appearance emphasizes its object character in contrast to its insect-like appearance.



The robot consists of ❷ twelve servo motors controlled by a ❶ Teensy LC micro-controller. The ❸ legs, made from PCB material, detect touch via capacitive plates and function as a switch that opens when broken.

merges with the final artifact – creating an unobtrusive interaction experience. In contrast, when using RWPs to design for confrontation, the designs should create concrete experiences or comprehensible situations for the humans in interaction. In this capacity, the RWP is used more concisely and may even be more noticeable in the final realization of the design.

For example, as an exploration of the RWP of constructive play and meaningful shapes, the **COMB** [P9] interface took reference to playful objects and constructive materials. Thus, it evokes creative associations, indicates reorganizability, and suggests construction and deconstruction. This confrontation aimed to determine if humans would become accustomed to functionality being represented by the form of the interface. Free exploration showed that they extrapolated the concept without further guidance and tried unintroduced forms and interactions. Observing such behavioral patterns due to new concepts allows researchers to conclude the effects on the humans in use. In this case, RWPs depict a known frame of reference which provides easy access to novel concepts.

In the case of **Undesigning Undo** as a design strategy [P6], human actors were confronted with speculative artifacts incorporating irreversibility in their design. For example, materials were destroyed due to the interaction, interface components were no longer accessible after initial interaction, or the human actors even had to destroy the interactive artifact themselves as part of the interaction. By removing otherwise available undo functionality, the actors were confronted with a fundamentally different approach to performing interactions, which triggered reflection and enforced an increased awareness while interacting.

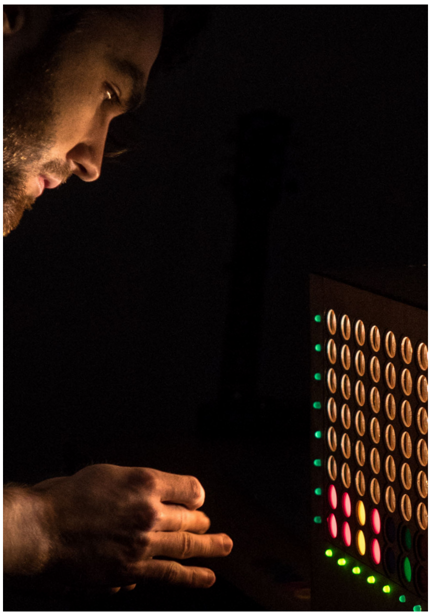
While the previous project explored irreversibility in a musical and social media interaction context to induce mindful action and reveal hidden processes, **Punishable AI** [P8] explored the human response to exaggerated anthropomorphization when interacting with a robot. In constructing a "Milgram-esque" experiment [90] in which a robot was punished during a learning task, the reflection on existential questions about the results of intertwining human and non-human interaction patterns and thus the ethical implications concerning the "existence" of a machine were triggered. Compared to the use of abstract commands or stimuli, the physical punishment – breaking a robot's legs – took place in relation to human ethical and social values and habits. Hence, the confrontation occurred on a different level.

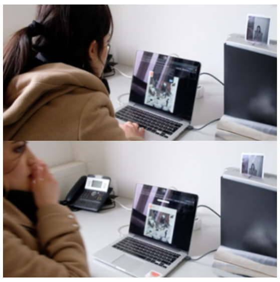
RWPs used inspirational

For both generative and confrontational purposes, the goal is to generate knowledge for later explorations. Therefore, RWPs are used as the source for generating designs – subtly merging with the interface – or for creating confrontation through comprehensibility, therefore being evident, apparent, manifest. The last purpose depicts the usage of RWPs in their true, unaltered nature but with the purpose to inspire and shape new ways of interactions – through exploration. The designs generated form a source of inspiration via their manifestation, the process of making [42, 137], and the experience of the hands-on exploration.

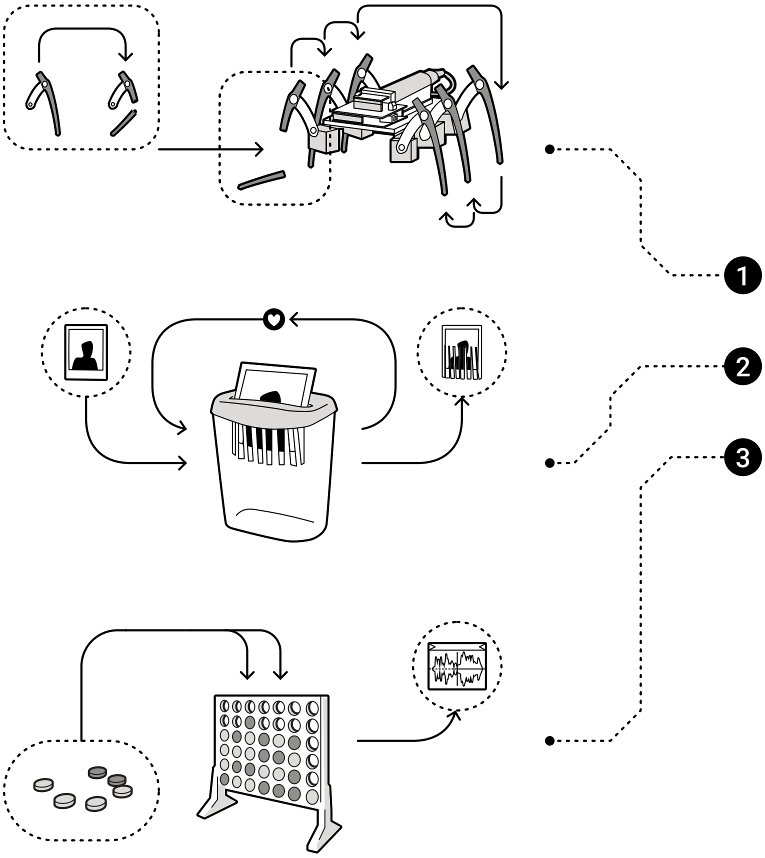
In this sense, the application of the RWP of social **Human Touch** [P3], as a short-term and relatively trivial interaction, was investigated in terms of its impact on the human experience

Undesigning Undo





Undesigning Undo explores aspects of causality and irreversibility as a design strategy in the context of tangible user interfaces. Instead of offering the user the familiar option of undo and redo actions, irreversible changes to the system are the result of the interaction. Consequently, conscious acting and reflective engagement were applied to adapt to and counteract the modified interaction flow.



Three design speculations explored different aspects of irreversibility.
❶ Materials were broken,
❷ objects were disintegrated, and
❸ interaction materials were inaccessible after first interactions.

in virtual environments when interacting with characters controlled by human or non-human entities (avatar/agent). Here, the RWP was quasi copied directly into the virtual realm, a physical copy of a hand, delivering a haptic stimulus in a socially interpreted context. While these studies were successful and the agents showed increased attributed agency, this also raised new questions. Among others, what other types of social interactions are appropriate and desirable besides brief touches in the context of greetings, and what alternative ways of technological mediation are conceivable.

Similarly, in the case of exploring **Traces of Use** [P2] in an urban interface context, passive artifacts representing different styles and forms of traces on concrete tiles were provided to human actors to investigate their understanding of such proposed interface elements. Through direct engagement with such artifacts, thoughts, ideas, and mental models were elicited that helped to understand how humans interpret the traces intended to serve as the central touchpoint for interaction. Through this exploration of the RWP and the gained inspiration, a basic understanding was established, ideas were gathered, and the subsequent design process was informed.

Concluding Remarks about RtD Purposes

The previous annotation shows, that through the use of RWP three main purposes pf the RtD practice are complemented (**T1**). When solving design issues, RWPs function as a resource for concepts, ideas, and artifacts. When exploring interfaces that use RWPs, the interaction and experience trigger associations, patterns of action and initialize a reflective engagement with technological speculation.

RWPs can therefore be used to serve as a blueprint, offering options of established interactions, designs, and comprehension already proved in the real-world context. While this can act as a starting point in the design process, they should not be considered pre-existing solutions for given problems but potential building blocks that need to be adapted and re-contextualized for new situations. In doing so, RWPs are used **generatively** within the RtD. Instead, the critical **confrontation** places the human in a situation in which they can not elude from and are therefore forced to form an opinion during this experience. Thus the design generates "dilemmas or confusions among users in such a way that users are encouraged to expand their interpretative horizons or rethink cultural norms" [9]. The advantage of using RWPs in an artifact's design is that a context is implicitly created that is relateable and inescapable via a purposeful familiarity. In the case of **inspiration**, on the other side, the purpose is not to create new designs by looking into the real world but to arrive at new questions, ideas and concepts by experiencing a re-imagined RWP in the form of a speculative artifact. Often these purposes go hand in hand since RtD processes iteratively repeat generation, confrontation, and inspiration.

While inspiration is the result of most design basis, RWPs keep the specific potential to integrate the individual and cultural context, which leads to the next annotation theme.

4.2 Making Use of Similarity Facets

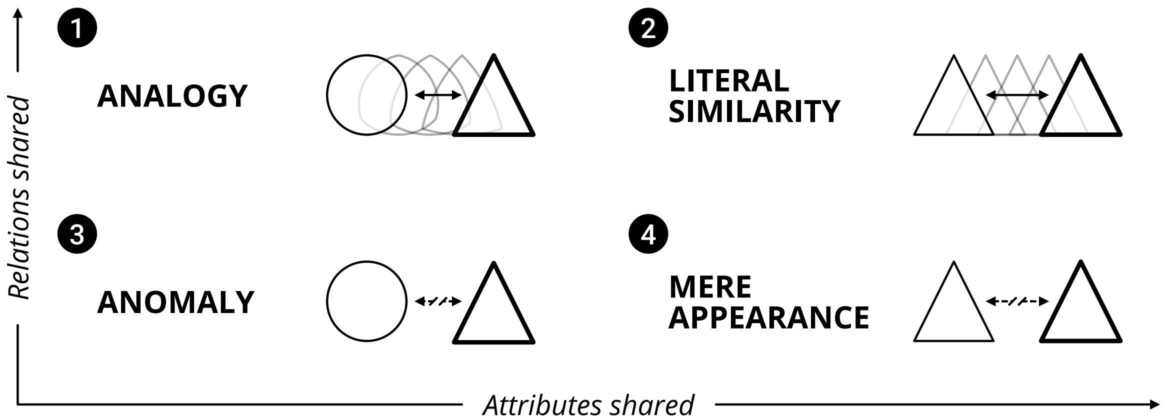


Figure 4.4: The transfer of RWPs to the design of speculative artifacts can occur in several different forms. Depending on the kind of transfer, attributes and relations are preserved or lost. Attributes in this context refer to whether it appears to be similar and relations to whether we understand it to be similar.

When implementing RWPs in the context of designing interfaces and interactions, conscious references between a source domain and a technology are constructed. Through this juxtaposition [19], the designer creates a carefully crafted interplay of associations, connotations, and interpretations. This approach is not only helpful in finding new and unexpected combinations of technological problems with RWPs (and thus contexts and interactions) but can be foremost instrumentalized consciously to shape how technology is conceived since "different kinds of similarity may have different psychological roles in transfer" [50].

As differentiated in the research on analogical reasoning and structure mapping, what is commonly referred to as analogies and metaphors is broken down more precisely into the following categories: (1) **Literal Similarity**, understanding something through a comparison which preserves all attributes and relations; (2) **Mere Appearance**, a comparison based mainly to exclusively on attributes; (3) **Analogy**, a comparison based primarily on the shared relations; (4) **Anomaly**, a comparison not sharing any relations or attributes.

While Gentner [50] still considered a fifth category – the Metaphor – which lies in between the differentiable edge cases of the similarity space, I will exclude the Metaphor for the sake of clarity – due to the overlap with the other facets. Nevertheless, the reader should keep in mind that a continuous space underlies these four categories, which means that intermediate states are conceivable, even if not considered explicitly.

Literal Similarity

When working with RWPs, the similarity between a source and a target domain is exploited in two ways. First, the selection process has the goal of finding either obvious or unexpected and non-evident references. Second, the translation of RWPs into an artifact is an active process in which designers define, through their decisions, which aspects of a chosen similarity are adopted – thus influencing how the similarity is reflected in the design and, therefore, to which degree and in which way it is perceivable. In using literal similarities, the RWPs and their transfer are about being close and evident in concept and design.

For example, during the examination of musical grid interfaces [P10], it became apparent that users frequently compared such devices to touchscreens – indicating an inherent similarity between the technologies. While they are similar in that they display musical information and enable interaction via the same pixels, the difference in resolution and input modality creates different usage situations and opportunities. By acknowledging the differences and the existing commonalities, the missing touch interaction patterns were identified and literally transferred to the **TouchGrid** [P7] interface to solve the apparent challenges such as navigation and menu access. As a result, a hybrid interface form was created in which the grid's literal similarity to touch-screen devices was further enhanced.

In the case of **Traces of Use** [P2], the challenge was to reconcile the desirable unobtrusive integration of technology with the required detectability of interactive technologies at historic sites. In assessing these places, it emerged that human activities are already indicated through traces of use on objects, surfaces, and materials. While these are often seen as passive marks of human interaction, these traces act as active signals of human behavior, as in desire paths [30]. In drawing on the signifying nature [95] of traces, their literal adoption into interface elements was explored. Their design indicates previous human use and implicitly suggests possible interaction patterns. Therefore, the similarity was exploited by taking qualities of material abrasion, surface finish changes, and discoloration to recreate traces in a technological setup literally.

The study of social interactions, such as handshakes and affirming touches, and their effect on and meaning for humans led to their exploration in the VR context and the literal replication of human anatomy and social procedures. Detailed aspects, such as the body temperature and the stiffness of the limbs and flesh, were considered when designing the silicone hand to replicate the experience of a real **Human Touch** [P3]. This artifact was then used to recreate the original behavior, actions, and experiences realistically. Therefore, small social interaction elements were incorporated in the VR experiences to give the impression that an actual social entity is involved in the interaction.

Mere Appearance

Using literal similarity leads to designs and concepts that carefully utilize aspects of both the appearance and context of the source RWP. Instead, instrumentalizing mere appearance in the design of the interface and interaction concept can detach the material used from its origin and recontextualize it. This opportunity allows for exploring established interface forms, the related interactions, and the underlying mental models in new contexts.

This approach was used in the case of **StringTouch** [P5], where the affordances of string instruments and inherent interaction patterns were investigated. After studying the instruments' layout, shapes, and interaction elements, the derived morphology was applied outside the original context of musical interaction. They were then explored in domains such as automotive interfaces and generic computer peripherals. As a result, benefits such as expressive interaction vocabulary, continuous rather than distinct interaction states, and interface structures that can be experienced through touch were introduced in these cases.

Analogy

When gradually moving away from the appearance-driven translation of RWPs, the field of analogies is opened up. In the previous cases, the patterns were recognized and adopted directly (cf. **Human Touch**) or adapted and re-contextualized but based on their visual appearance and the resulting affordances (cf. **StringTouch**). In comparison, analogies are more free interpretations and adaptions of the RWP, choosing the relations specifically to construct an intended interaction concept.

When approaching the idea of using shape as a discriminator for functionality in the interface context, the main design of the **COMB** [P9] interface was determined by the standard design principles from general grid controllers [P10]. Thus, the source RWP, namely building blocks such as LEGO bricks [51, 96], was not directly copied or reutilized. Instead, primarily the idea of constructability and the resulting modularity of the interface was adapted to the artifact. Other aspects of the source RWP, such as the construction in three-dimensional space or the granularity and diversity of the individual building blocks, were ignored or modified. Although the resulting design does not directly resemble the RWP, it subtly stimulates intended and inferred interactions through, among other things, the magnetically detachable connections and symbolic shapes used as indicators of functionality.

Similarly, the interaction of falconers and falcons was not meticulously transferred to the context of human drone interaction in **Lure the Drones** [P4]. This mismatch starts with apparent aspects, such as drones looking, moving, and acting differently from birds, but is even more evident in the differences regarding the interaction setup. While in the case of falconry, the arm offered fulfills the purpose of providing the bird a place to sit after being lured back, it has no symbolic meaning in the bird's training. Instead, they are trained on visual, motion-based patterns (moving objects that simulate prey). However, the iconic pose, the arm offered as a landing platform, with its high recognition value, has imprinted itself on the collective memory – decoded as a call to return. The analogical transfer shows in the freedom to adapt and collage the ideas of falconry-based gestures combined with other patterns of animal training and social interaction such as eye contact to indicate attention or hand gestures to specify commands and actions.

Anomaly

While the previous facets describe how similarity is transmitted by emphasizing the aspects in which the artifact is considered similar to the selected RWP, the design, when based on anomalies, can be defined by relations that contradict typical assumptions.

The project **Undesigning Undo** [P6] specifically introduced irreversibility in the HCI context – where reversibility is typically the norm. Thus, the RWP of causality with its clear functional criteria contradicts the expectations with which humans usually approach HCI interfaces and systems. Instead of having the possibility to undo and redo an action, there was either a lasting change of the material or the material itself was no longer reachable and thus available for later changes. By introducing this mismatch between conceptual understanding, workflows, and habits, the new system forced users to change their regular routines for interacting with technology and instead shift their thinking from retrospective analysis to prospective anticipation and from thoughtless action to conscious interaction.

In the same manner, the punishment used in **Punishable AI** [P8] contradicts what is considered appropriate and logical in interacting with social technologies. In that sense, the concept is analogical, drawing parallels between the natural learning process and machine learning and thus between the intelligence of beings and machines. While the analogical design does not imply a full transfer of all relations, Punishable AI consciously counteracts these relations and their conceptualization. Instead, it stresses the discrepancy of the conceptualization of the machine and the required interaction. This mismatch is manifested in (1) the technical capabilities and the assumed emotional intelligence in response to the scolding, (2) the machine's "fear" triggered by a technical stimulus, and (3) the required ability of a machine's body awareness in breaking its legs. Thus, the source and target domains are estranged, using the ostracized punishment as an unexpected relation, which is an anomaly in the design.

Concluding Remarks about the Similarity Facets

As described above, the transfer of an identified RWP can take place in four different ways (**T2**). Further, the thereby created comparison between a RWP and a technology serves two different functions in the design process. By acknowledging the similarity between existing technologies and ubiquitous RWPs, (1) the designer can utilize the discovered similarity to stimulate new concepts and ideas and draw from this resource, and (2) the humans using the technology are guided towards comprehensible interactions by their prior knowledge.

However, perhaps more importantly, with the analytical understanding from cognitive science, similarities can be chosen consciously. Thus, they can have specific properties of the whole spectrum between typical or atypical, depending on the objectives in designing a technological artifact in relation to the research questions. In critical and speculative design, intending to provoke and stimulate, this helps to "design something with just the right 'slight strangeness' to be productive" [9]. This opportunity allows designers to identify and replicate existing and context-immanent interactions and interface structures and draw from novel and non-obvious juxtapositions. Thereby, new and exciting interaction opportunities can be discovered, and similarities can be defined, which counteract and contradict and therefore disclose the expectations humans bring to the interaction with technologies.

At a high level, this means shaping the relation we experience as humans as we interact with technology, leading to the next annotation theme.

4.3 Shaping Human-Technology Relations

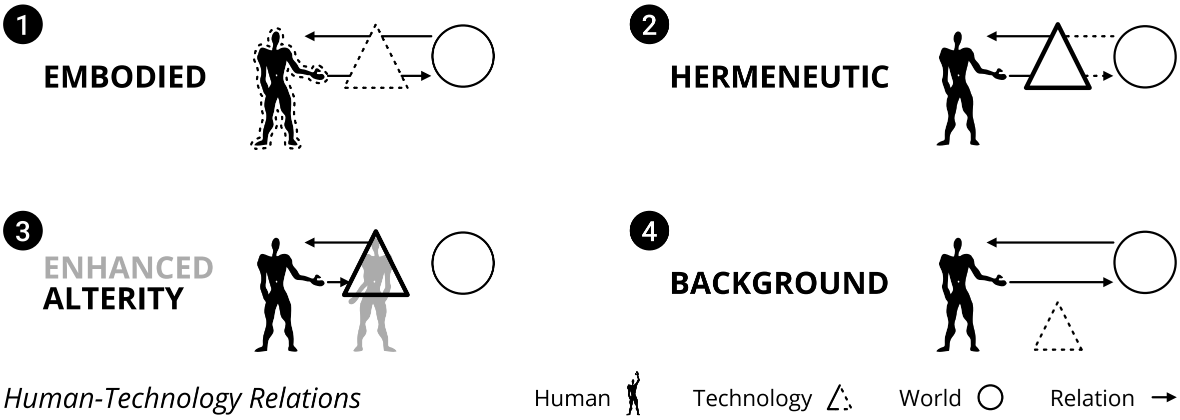


Figure 4.5: Don Ihde's [69] postphenomenological perspective describes human-technology relations in four forms. These relations have been extended (e.g. cyborg rel. [126]) but the main four forms are sufficient to describe the relations in this work. As a variation of ❸, *enhanced alterity* describes the interaction with a technology attributed a mind or social presence.

Since humans "are always directed toward reality" [126], a human-technology-world relation is implicitly created in interaction with any technology. As explained earlier, this relation can be consciously shaped through the artifact's juxtaposition of RWPs and technology.

To understand these emerging human-technology relations, the perspectives created in the field of postphenomenology [69] are revealing. The techno-philosophical line of thought deals with the "bodily relations to technologies" [1] and contemplates "the extent to which both, the human and the material world, existentially depend on the relation to each other" [43]. Postphenomenology offers a framework that guides the conceptualization and understanding of the mediating character between technology and the lifeworld as well as the influences technologies have on the human actors. As a result, design can be understood as an active part of human-technology relations, and its effect on this relation has to be acknowledged. Following this thought, one can ascribe to design – in its materiality and immateriality – an agency over human beings in interaction [43].

With this perspective in mind, I will comment on how the post-phenomenological understanding of the human-technology relation is expressed in the works included in this thesis. The artifacts presented and the therein present RWPs are interpreted as individual expressions of Ohlin's postphenomenological framework [97], which combines the theories of Ihde [69] and Verbeek [127] in the following aspects of (1) relations, which describe how close and perceivable technology is when mediating between humans and the lifeworld (cyborg [126], embodied, hermeneutic, alterity, enhanced alterity [133], augmentation [125], immersion [125], background), and (2) **Experiential** and **Existential Perspectives**, which distinguishes the focal point either on the perception through (Experience) or involvement in (Existence) an interaction.

Experience – Shaping Human Perception and Interpretation

The Experience Perspective of Ohlin's framework [97] focuses on human perception and interpretation when interacting with or through technology. This focus helps to understand how technology can either amplify or reduce the human perception of the lifeworld or the technological system in use, depending on the technology's design and thus the use of RWPs.

From this postphenomenological perspective, **Traces of Use** [P2] represents a classic alterity human-technology relation. Technology, in this case, is something "other" – a technology that is used "directly within its own system" [128]. However, the RWP used transforms the perception and interpretation, that is, the experience of the technological artifact. While generic input devices are often out of context with their environment, the Traces of Use interfaces are integrated into their material environment, building on the meaningful nature of traces to amplify the inherent interpretability of the technology. Through this, the traces signal interaction and indicate how actions are performed.

Similarly, the interaction with standard musical interfaces and controllers also represent classic alterity relations – humans interacting with technologies that are something "other" not being mediations to the lifeworld. Further, the related interactions are difficult to "read" from the outside since the generic input actions cannot be decoded without knowledge about the application and interaction context. However, when the **COMB** [P9] interface was enhanced through its functionality being determined by its form, this new aspect amplifies the lifeworld presence of previously hidden information. Thus, the RWP transforms the encapsulated nature of information into an entity present in the physical world that can be perceived, observed, and imitated – adding hermeneutic qualities to the perception of the artifact.

In the case of **Human Touch** [P3], the classic four human-technology relations defined by Don Ihde [69] reach their limit since technology no longer mediates between the human and the lifeworld but replaces the lifeworld as the user's reality. Nevertheless, suppose the focus is on the perception of the technological agents that interact with the human and exclude the VR setup. In that case, the relation is an alterity relation since the agents are perceived as something other than human, as technological entities. However, through the incorporation of social touch, the experience is transformed to be perceived as "more" real, acknowledging the technology a social presence, an independent mind, and agency within the virtual world – blurring the border between human and artificial actants.

In the same way, **Punishable AI** [P8] transforms the alterity relation through the implemented anthropomorphization and the RWP of punishment and thus changes the human perception of the machine. The ambivalence of the robot's technical appearance, the anthropomorphizing interaction, and the socially contradictory connotation created the impression of a seemingly "living" being simultaneously classified as an inanimate thing to justify the action of physical punishment that was performed on it. This ambiguity challenged the human experience and conceptualization of the machine and opened moral and societal deliberation in interaction with it. By opening up this ethical layer, the alterity relation to a technology as something “other” changed to an enhanced alterity – interpreting the former object as an entity with a mind and social presence. This change is not just about transforming the perception of a technological system but ultimately about the ontological question of how such interactions transform us as humans. [43].

Existence – Shaping Human Action and Involvement

On the other hand, the Existence Perspective is concerned with the influence technology has on human involvement and actions in the context of technologies. Through the design of technology, people are invited to perform actions and incorporate technologies into their practices but are also inhibited from interacting in other ways.

Intertwined with the Punishable AI project, **Undesigning Undo** [P6] instrumentalizes the resulting ambiguity of involvement through the RWP of irreversibility. On the one hand, the interaction is inhibiting by its finality; on the other hand, it is inviting as it stimulates conscious action and reflective engagement. The RWP of irreversibility, through the underlying material changes, interrupts the interaction flow and thus emphasizes human-technology relations in the background – bringing them to the attention during the interaction. These factors transform the human involvement and create a dichotomy between action and non-action, materiality and finiteness. In this way, the agency of the artifact over the human actor becomes evident, highlighting technologies’ active role in this relation.

In the case of **Lure the Drones** [P4], the technology, which has previously been a separating layer in the interaction with the world (hermeneutic relation), was dissolved to allow for direct interaction within the lifeworld (embodied relation). Further, the interaction invites one to look around, point at, and directly act within the surrounding world, engaging the human in an interaction embedded in their bodily existence. Using the RWP helped to conceptualize alternative human-technology relations in the setup of human drone interaction; as a result, the human is directly involved in the world when interacting – thus, human and technology form a “unity [that] is directed at the world” [125].

StringTouch [P5], as previously COMB, presents the classic alterity relation of a generic control surface. While the use of the RWP improves the interface’s interpretability, the improvement of its interaction capabilities is also of interest. Through the deduced morphology, the human actor is invited to perform novel actions with an inherent complexity that differs from the touch-screens interactions. The static glass surface of the screen is inhibiting because it can be touched but not deformed, swiped but not grasped, felt but not distinguished by touch. Thus, using deformable materials and the deduced morphology that materializes in the surface structure and textures enable and invite human action and involvement.

Congruent with this, the **TouchGrid** interface expands its involvement by increasing the available interaction vocabulary. Thus, in this typical alterity relation, an inviting involvement is created through the reuse of the familiar usage situation derived from touch interaction. Interaction patterns that can feel complex and cumbersome when executed as button press combinations are designed as more direct and natural through relying on familiar touch gestures such as swipe actions. In its hybrid form, the TouchGrid interface strives to maximize the inviting character without inhibiting former qualities.

Concluding Remarks about Shaping Human-Technology Relations

As annotated above, the projects demonstrate the effect of using RWPs on the created human-technology relation (**T3**). In the described cases, the usage of RWPs was intended to craft closeness and relatability between humans and technology. The usage of RWPs creates rich experiences which are implicitly and explicitly contextually loaded, which is reflected in the created relation. These relations were designed to be unobtrusive in quality, natural to the human condition, functional to expand the possibilities of human interaction with technology, and existential in the sense of contemplating how being human is changing in parallel with the technological developments we are chasing.

The speculative manner of the projects allows researchers to ask how a close and tightly coupled human-technology relation could and should look like and if certain technological developments and trends are desirable. RWPs can therefore be used to reinforce an alterity that confronts the human in dialogue with the machine with the question of the actual technicality of the artifact – what is a thing if it is treated humanly? RWPs can further shift a technology relation previously located hidden in the background to the foreground by disclosing processes – are we completely aware of technological processes and implications when interacting with, e.g., social media platforms? But first and foremost, embodied and hermeneutic relations can be created that blend technology and interaction with the human environment, therein present and familiar processes, and a thorough understanding of the lifeworld.

Focusing on these human-technology relation aspects, the usage of RWPs in design is understood as an application of the post-phenomenological understanding of technology in the HCI context as proposed by Hauser et al. [58], thus contemplating “desirable technological futures and who ‘homo digitalis’ should be in those futures” [43].

4.4 Summary

When reexamining the three presented themes of annotation (**T1-T3**), one can spot their close interplay. When thinking about shaping the human-technology relation as a project goal, the question of the research purpose immediately arises, which in turn dictates the selection of and the transfer through the similarity facets under consideration.

When designing for confrontation, e.g., a relation should be created that is as close to the human as possible to generate the maximum effect. In that sense, embodiment and enhanced alterity are preferable over background and hermeneutic relations. If the objective is to create stimulation through provocation, finding anomalies in the designed similarity can fertilize the intended relation and create tension that is unloaded during the confrontation of the actor with the designed artifact as in the case of **Punishable AI** and **Undesigning Undo**. This is especially useful when designing for critical reflection and when speculating about the development of future technologies.

If the objective instead is to generate and inspire new interface concepts, the selection of RWPs can be guided by the similarity space. Through the emerging patterns, when exploiting the similarities between technology and RWPs, systems are created that offer the designer rich resources to draw from ([P5], [P4]), the interacting human a guiding reference ([P2], [P7]) as well as merge with the experience expected and subconsciously assumed ([P9], [P3]).

As such, the presented annotation themes set forth three perspectives to conceptualize the use and the effects of RWPs in the design of HCI systems. Thus, they can guide the design process in an informed manner.

T1: Contemplating RtD Purposes RWPs in the design of speculative artifacts can be used (1) as a resource when **generating** new concepts, ideas, and designs, (2) for creating **confrontation** which is still comprehensible, and (3) as a starting point for discussing designs functioning as an **inspirational** resource.

T2: Making Use of Similarity Facets Selecting RWPs and juxtapose them intentionally with the technological context can (1) **structure** the process of approaching design (looking for dis/similarity or un/relatedness) and (2) can be utilized in **constructing** situations and associations through the conscious transfer of RWPs into speculative artifacts.

T3: Shaping Human Technology Relation The human-technology relation is shaped via the RWPs used and the juxtaposition of design with technology. This helps to explore how (1) the created relations, expressed in closeness between technology and humans, and (2) the **involvement** and **perception** influence the interaction with technologies.

5
DISCUSSION & CONCLUSION

> *After all, the extent to which digital technology shapes who we are means that whoever shapes technology, puts the chisel on humanity.*
>
> **– Christopher Frauenberger [43]**

5.1 Discussion

As outlined in the previous chapters, using RWPs in the design process of HCI systems and especially in the crafting of speculative artifacts can have several advantages and benefits. However, it must be emphasized that similar advantages might possibly be achieved by following alternative programmatic approaches. Thus, this thesis can only report about the within experienced benefits. Therefore, in the following discussion, I will reflect on the programmatic approach itself and on the questions of (1) advantages through self-limitation, (2) conceptualizing instead of problem-solving, and (3) the integration of this design approach within the research practice of upcoming HCI waves. Finally, I will conclude with a brief reflection on the scope and implications of this work.

5.1.1 Real-World Patterns in Research through Design

The eight included projects show that following the presented programmatic approach in designing HCI systems is a supportive, and stimulating process in the RtD method. I demonstrated that beyond a simple way of inspiring the physical appearance of designs, using RWPs can be instrumental in further aspects of RtD purposes; this is acting in "generative, evaluative, inspirational, descriptive, [or] critical" [65] ways (**Q1**). Since we as humans are always related to the world through perception and interpretation, this cognitive process of "structure-mapping is inherent in all of our thought processes, and especially in the permanent construction of meaning that we engage in effortlessly as we conceive the world around us" [40]. Hence, incorporating abstract connections – thinking about something in terms of something else – is per se a human activity. Utilizing this capability in applying and transferring RWPs into artifacts equips designers with a tool to consciously shape the interpretation during the interaction (**Q2**). This is done by consciously choosing RWPs with the objective to fulfill or contradict the expectations and assumptions of the interacting humans or by selectively executing the transfer of shared properties and relations. This shaping of human expectations finally affects the human-technology relations of such systems (**Q3**). Here, the postphenomenological perspective helps to conceptualize and name the generated relations and resulting implications. As such I demonstrated that the usage of RWPs is able to bring former background relations to humans' attention [P6], to enhance alterity [P3] or to intentionally create an ambiguity in (enhanced-)alterity [P8].

Through the provided annotation, I outlined three essential perspectives that depict tools in using RWPs to inform HCI. In acknowledging the effect on the human-technology relation, this is doing postphenomenology through design. And, therefore, provides a tool that enables designers and researchers to draw "on postphenomenology in a generative way for design" [58] which is currently an underrepresented approach in HCI research.

5.1.2 Approach Design Complexity by Self-Limitation

When reflecting on the work presented, the question arises why such orthodox self-limitation – focusing exclusively on Real-World Patterns as a source of inspiration and reference – should be considered beneficial rather than an unnecessary constraint in the design process. Generally, all design suffers from potentially limitless resources and approaches to draw ideas from and the considerations to take into account. Due to this infinite space of possibilities and opportunities, designers face an unsolvable problem: "it is not possible to exhaustively explore them for all potentially useful information" [117]. So using a specific design approach acts as a filter that narrows the possibility space and converges to a design solution for a particular problem. This effect is not a new phenomenon but can be considered equivalent to how, e.g., design schools and professors shape their students by teaching and training a specific way of thinking design and approaching problem-solving. In that sense, the big design schools such as the Bauhaus [101] act as large-scale filters. But already on the small scale, "requirements, conditions, conventions, rules, [and] demands" [11] narrow down the possibility space in the creative process, and even prototyping itself acts as a filter for "the qualities in which designers are interested" [84].

Beyond that, approaching design challenges programmatically forces researchers and designers to come up with unexpected interrelations between problem and solution and thus technology and concept. In addition to principles and strategies inherent to their discipline, designers are prompted to consider seemingly extraneous references, as in this case, from the real world. Such strategies in the process of designing are expedient and can be regarded as "a source of inspiration rather than a limitation" [111] since "constraints can simultaneously restrain and enable creative thought and action" [11]. In that sense, they lead to otherwise unconsidered solutions, and concepts and allow the designer to create a novel perspective [102] that differs from the usual and unconsciously prevailing mainstream, with the constraint acting as an enabler of the creative thought [16].

Thinking in terms of RWPs leads the design to implicitly integrate an inherent familiarity by asking questions such as: "What existing things, situations, or mechanisms are similar to the situation to be solved using technology?", "What underlying principles link already familiar patterns in the real world with specific aspects of a novel technology?", or "How does the continuation and exaggeration of existing paradigms can strain the conceptualization of technology and the human relation to it?”. In line with this, the presented work demonstrated the following aspects: First, the juxtaposition of future technology and non-related RWPs, such as in the case of **StringTouch** [P5] and **Punishable AI** [P8], led to novel interaction concepts and the critical reflection on existing paradigms. Second, as seen in **TouchGrid** [P7] and **COMB** [P9], the hybridization of existing technologies created interactions that stretched the possibilities and the understanding of the source technology by adding new levels of interaction capabilities seamlessly interwoven with familiar interactions. And third, the recognition of parallels or conflicts between phenomena observed in the real world concerning aspects of technology, technological entities, and the interaction between both might lead to (a) a critical examination of established HCI paradigms as with **Undesigning Undo** [P6], (b) new forms of design affordances or signifiers for interfaces as in the case of **Traces of Use** [P2], and (c) novel interaction concepts as shown with **Lure the Drones** [P4].

5.1.3 Tame Problems vs. Wicked Problems

Creating such a strong conceptual foundation to motivate and inform HCI interfaces might seem unnecessarily complex for most HCI problems. However, the conceptual work and the development of speculative artifacts present a significant opportunity when leaving the field of tame problems and entering the field of wicked problems [107]. Since wicked problems are problems that “cannot be addressed using conventional methods of problem solving because of their uncertain boundaries, conflicting and incomplete requirements, and systemic complexities, such that the attempt to solve one problem may create others elsewhere” [119], designing for unconsidered interaction paradigms and alternative technological futures can be considered a wicked problem. Because there are no well-defined objectives and not all influencing factors are known, this area of research is fundamentally different from usability-centered research, which is tame in the sense that it has a “specific technical terminology [...]; a set of trusted techniques, methods, and theories that can be assessed and discussed; and [...] a communal sense of what to strive for” [36].

The result – especially when considering future technologies – is that it is not primarily a matter of creating a solution to a problem but instead of first manifesting concepts that enable discussion based on the created experience. In that sense, through design, wicked problems can be transformed into new situations with new perspectives disclosing new opportunities, possibilities, and interrelations [119]. This change in perspective is necessary since science is concerned with the “existing and the universal, [whereas] design aims to create the yet-unexisting and the particular” [98]. The creative design practice, due to the outlined reasons, can overcome some central aspects of wicked problems and therefore must be employed [137]. The opportunity of design speculations consists in the fact that physical artifacts are created, and by engaging with them, the potential for confrontation and inspiration is generated – “assessing the development of objects not against whether they fit into how things are now, but [based on] the desirability of the changes they encourage” [32].

When we change a wicked problem's framing by asking "How is the human affected through ..." instead of "How can we improve ...", the problem suddenly turns into a "What if ..." scenario and thus into a research-oriented [37] design exploration [26]. The added value in using RWPs is that it creates comprehensibility and familiarity in the initially wicked context – giving points of reference and clarity in a net of unknown variables. Now the disposition through using RWPs helps relate with the exploration. Acting in such a context can be related to prior experiences [P2, P6, P9], societal norms and moral standards [P8], or known mechanisms and patterns of interaction [P3, P4, P7]. Thus, the speculative artifact "becomes a statement of what is possible, what would be desirable or ideal, or just to show alternatives and examples" [21] but always within a known frame of reference. Designing with RWPs represents a way of designing for wicked problems that is prospective in that it deals with future technologies and challenges but retrospective in its way of building on what is understood – exploring the space between the known and the unknown.

5.1.4 From the Third to the Fourth Wave of HCI

Due to the exploratory character of the research conducted with speculative artifacts, as described before, the knowledge generated throughout these experiments is primarily of intermediary [66] quality, which is "knowledge that lives in between generalisable theories and single instances" [43]. While this can seem problematic from the scientific standpoint, HCI itself – especially in the context of third-wave HCI with its "situatedness, values and embodiment" [43] – must face the accusation of being hard to generalize, especially when confronted with ontological questions posed by upcoming technologies such as artificial intelligence and virtual reality. However, this does not mean that the experiments and associated results are not valuable, but that it is essential to situate and understand the knowledge generated from a standpoint epistemological view [55]. Because this approach does not represent the mainstream way of doing research, the associated findings, although highly individual, have their own informative character, shining a light on underrepresented and under-explored concepts and design ideas.

This approach further helps to design for more than just the utility and consider "the broader roles of technology in everyday life" [97] and society. RWPs can, through their ability to put the human in direct confrontation with a socio-technological concept, create some kind of "Dasein (being-in-the-world) [which] could be interpreted as an ethical take on Heidegger's philosophy" [43] and depicts the opposite of the idea that humans are alienated or distanced from the world due to the use of technologies [43]. Therefore, when we as HCI researchers design a technology "it is not things that are to be designed, but rather the interactions between humans and things" [125]. And even beyond that, as put by Frauenberger in his discussion on the fourth wave of HCI: "to shape who we want to be in this world, we should be designing meaningful relations, not user experiences" [43]. In this sense, the speculative artifacts presented focus primarily on the aforementioned meaningful relation using RWPs, rather than on typical UX objectives. This is understanding technology by (a) relating it to one's own experience and lifeworld consistency [P2, P7], (b) being involved through existential and moral demands [P6, P8], or (c) through recognizing the convergence of acting within technology and the lifeworld [P3, P4, P5].

Further, in acknowledging the agency of technology and its influence on the interacting humans, the meaningful relations are established through both the human and the technology acting – "subjects and objects do not pre-exist their relatings, but rather, come to matter through the ongoing interaction – or intra-action – of ontologically inseparable entities" [105].

5.2 Conclusion

In this thesis, I presented and discussed projects concerned with the objective to explore the programmatic approach of using Real-World Patterns to inform HCI systems in the form of speculative artifacts. The projects presented covered various HCI fields, from VR research to human-robot interaction and tangible interfaces. In an attempt to generalize the lessons learned in the application of this design approach, I have explained how the use of RWPs and their transfer into speculative artifacts complements the purposes within the practice of Research through Design, can intentionally leverage the entirety of the similarity space in the creation of so-called "analogical" and "metaphorical" designs, and has an impact on the human-technology relation that is fundamentally determined by the inherent familiarity of the design concepts.

While this design approach can help structure the creative process – defining a clear frame of action and offering a repeatable pattern of approaching design – the main advantage, in my opinion, lies in the opportunity to contemplate topics, themes, and technologies that are on the verge. Here, the novelty and the potential temporal distance of such future technologies depict major unknowns in the design process, complicating defining objectives, needs, and requirements. Approaching such topics via the medium of speculative artifacts enables us as researchers to focus – beyond technological perspectives – on societal factors. Such speculations allow us to enact and experience the consequences of design decisions even before the target technologies arrived.

While this may seem like an artistic and design-oriented activity [7], I think it is an essential part of what technology research should be, which is being concerned with humans and their inter-relation with technology. What we can currently observe and witness are interaction paradigms being entrenched, which will heavily dictate how future humans will encounter technology. Anthropomorphizing of everyday technologies, concealing underlying processes, and the automation of everyday activities are intended to straighten out and facilitate the experience of humans interacting with technologies but can also lead to developments in which humans are ultimately further distanced from technology and the lifeworld. The design speculations presented in this work do not depict ready-to-take solutions and can themselves be accused of making the same mistake – enclosing technological aspects behind a conceptual facade. However, in their speculative nature, they overcome the pretense of being a solution and instead attempt to give researchers an inspirational and critical glimpse of “what might come”, “how it might look” and thus hopefully positively reflecting on later designs “yet to come”.

In that sense, the presented projects demonstrated that this programmatic design approach could take off the blinkers twice in HCI research. First, acknowledging and emphasizing possible future scenarios and developments, and second, recognizing the value of already existing and ubiquitous non-technological or non-related human-created artifacts, processes, and conventions. In this way, the value and richness of human cultural heritage are appreciated, recognizing how the world shapes us as humans and how we, in turn, shape the world in which we live. Therefore, using Real-World Patterns to inform HCI provides a programmatic approach to utilize this opportunity in the design of computer systems and interfaces. The three provided annotation themes depict perspectives which are instructive regarding the application of the process, which was exemplified by the eight presented projects. Finally, this approach offers an alternative perspective on the development of technologies beyond already existing technological solutions.

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Glossary

Actor An actor is a human involved in an interaction with a technological system, device, or context. The term actor is used instead of other familiar terms, such as user, since involvement with technology often appears outside what would be considered a typical usage scenario – as understood in "using a product". The term originates from Actor-Network-Theory [83], which describes both the human and non-human entities involved in an interaction. In the context of this thesis, the term actor is used for human actors, if not specified otherwise.

Artifact An artifact describes a human-made material object. Other immaterial products of human workmanship are not considered artifacts in this thesis.

Human Computer Interaction (HCI) Human Computer Interaction is the academic and design discipline concerned with the study and development of computer technology for human use. HCI as a discipline overlaps with computer science, psychology, and other studies such as sociology [28].

Real-World Pattern (RWP) Real-World Patterns are familiar objects and concepts that originate from human culture or the natural world. For example, causality as a principle of nature is considered an immaterial Real-World Pattern, as it is familiar to humans. Artifacts such as musical instruments can be considered as an example of a material RWP, since they are ubiquitous objects across cultures.

Research through Design (RtD) Research through Design is generally understood as doing research by doing design. This means, generating knowledge through the process of designing [139]. The term is used in this thesis to refer to various disciplines in the realm of RtD, as for example: speculative design, critical design, ludic design, reflective design, design fiction, and others. They all share an exploratory approach and often have a focus on intermediary knowledge production.

Tangible User Interface (TUI) Tangible User Interfaces are computer interfaces that are physically present as artifacts in the real world. Typically they represent a strong bond between the object and the associated digital system to be controlled. As such, they allow the manipulation and control of data or parameters via object manipulation such as movement, rotation, or other object inherent activities.

User Experience (UX) User Experiences are "meaningful, personally encountered events" [57]; this term originates from product development to classify objectives in the design of services and products. HCI adopted the term to measure aspects of user interaction that are not quantifiable.

Virtual Reality (VR) Virtual Reality is considered an experience situated on the reality-virtuality continuum defined by Milgram [89]. Virtual Reality fluidly fades into so-called Mixed Reality experiences (XR) when a varying degree of virtuality or reality is involved. As such, experiences of this type can either completely use virtual worlds or utilize physical objects and the surrounding environment.

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Original Contributing Publications

The research within this thesis would not have been possible without my supervisor, colleagues, and the students I supervised. Table 5.1 (on pages 63 and 64) clarifies my own and others' contributions to the included projects.

	My Contribution	
[P1]	I co-developed the concept together with L. Hirsch, contributed to the data analysis, supported the paper writing, and provided conceptual drawings and visualizations for the pictorial.	L. Hirsch was project lead, leading author, conducted the focus group, and did the initial field exploration. F. Bemman implemented the required web tool to run the study. A. Butz gave feedback regarding the paper.
[P2]	Together with L.Hirsch I explored the prototyping and implementation, further, I helped with writing the paper with a focus on the design rationale part, and compiled the statistics.	L. Hirsch was the project lead, conducted the user study, did the qualitative analysis, and was the leading author. A. Butz provided feedback regarding the paper.
[P3]	I supported D. Neumann in prototyping the artifact, co-developed the concept with the other authors, and together with M. Hoppe led the paper writing process.	M. Hoppe led the project and came up with the initial research idea. D. Neumann did the implementation and run the study. T. Machulla provided support regarding the statistics. S. Streuber supported the project development and A. Schmidt provided feedback on concept and paper.
[P6]	I developed the main idea and the individual project concepts, co-designed and co-implemented the three artifacts together with the students (T. Fütterer, S. Bouzir, P. Kim), and led the paper writing process.	N. Terzimehić helped in writing the paper and developing the concept. T. Döring supported the paper writing. Further, I received conceptual help and support from D. Buschek, and A. Wiethoff. The students executed the individual experiments.
[P4]	I came up with the initial idea and developed the concept together with K. Holländer. I was the leading author and project lead.	K. Holländer helped in writing the paper. The idea arose from a discourse with H. Drewes.
[P5]	I came up with the final project concept, developed the StringTouch prototype, the underlying technological concept, and the process-specific procedures. Further, I investigated the morphology of string instruments and associated interaction vocabularies, and was the project lead and leading author in the paper writing process.	The idea originated from a project with R. Martin, A. Schenker, and B. Vogler. The study was run by A. Gehlisch, P. Holinski, N. Kraler, and K. Rupp. Further I was supported in writing the paper by S. Rümelin and A. Wiethoff.

[P7]	I came up with the initial project idea, developed the hardware prototypes, and expanded on the student's firmware implementation for the final prototype. Further, I was the leading author, and conducted and evaluated the online study.	S. Unger implemented the first firmware for the prototype. A. Wiethoff supported me in writing the paper and project feedback.
[P8]	I developed the main concept, led the project, was the leading author, implemented the artifact's basic structure and firmware, and did the study evaluation and analysis together with S. Völkel.	P. Kim conducted the study and helped in the implementation process. S. Völkel supported the study development, methodology, and paper writing. E. Naphausen, A. Muxel, and A. Wiethoff provided feedback on the paper.
[P9]	I came up with the project concept, implemented the artifact, run the user studies, and led the paper writing.	A. Wiethoff provided feedback on the work, the publication and helped to write the paper's introduction and conclusion.
[P10]	I came up with the project focus and idea, did the literature review, collected and analyzed the data set, conducted the online expert study, and was the main author.	A. Wiethoff provided feedback on the work and the publication.
[P11]	I came up with the project focus and idea, collected and analyzed manufacturer data and interviews, executed the online expert study, and led the paper writing.	A. Wiethoff provided feedback on the work and the publication.

Table 5.1: Clarification of my own and others' contribution on the projects included in this thesis.

Undesigning Undo: Irreversible Interactions as a Design Strategy

BEAT ROSSMY, LMU Munich, Germany
NAĐA TERZIMEHIĆ, LMU Munich, Germany
TANJA DÖRING, University of Bremen, Germany
DANIEL BUSCHEK, University of Bayreuth, Germany
ALEXANDER WIETHOFF, LMU Munich, Germany

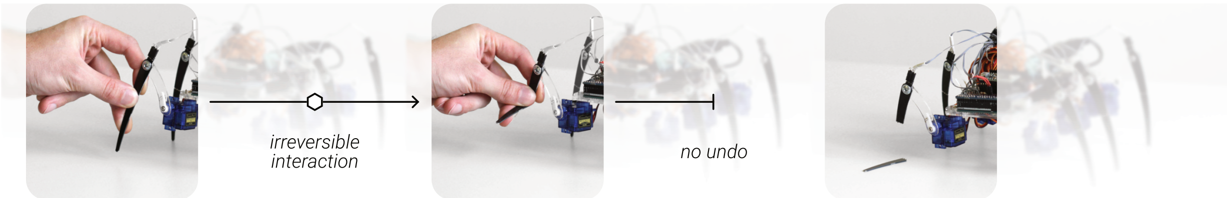

Fig. 1. Irreversibility is an inherent feature of the physical world, but is disregarded in current HCI research. We rediscover and appropriate this alleged deficiency and amplify it as an inherent material property in the design of interactive systems.

Despite irreversibility being omnipresent in the physical world, research on irreversibility in computing systems has been surprisingly sparse. In fact, user freedom – provided by the undo functionality – is considered to be a pillar of usable systems, overcoming irreversibility in the digital realm. Within this paper, we set up a thought experiment on undesigning the undo feature from physical computing systems (tangibles, robots, etc). First, we present three exploratory design speculations, each utilizing irreversibility as an inherent feature of the physical world. We elaborate on the concept of irreversible interactions by connecting our work with critical HCI discourses and by deducing *altering*, *creating* and *destructing* as design strategies. Finally, we discuss irreversibility as a design element for self-reflection, meaningful acting and a sustainable relationship with technology. Overall, we contribute with a first comprehensive conceptualization and discussion of irreversible interactions in HCI.

CCS Concepts: • **Human-centered computing** → **Interaction design theory, concepts and paradigms**.

Additional Key Words and Phrases: Speculative Design, Design Strategies, Irreversibility, Causality, Tangible User Interfaces, Reality-Based Interaction, Robotic Interfaces

1 INTRODUCTION

Irreversibility is surprisingly little understood as a design factor in HCI, even though it is ubiquitous in the real world and thus in human[1] interaction with it. Particularly causality is a fundamental keystone in learning about the inmost mechanisms of the world during childhood development [43]. For example, if a child breaks a glass, they learn that the glass remains broken.

However, in terms of causality and irreversibility, there exists a fundamental mismatch between interactions in reality and in the context of HCI systems. One of the fundamental HCI heuristics [73] postulates that *user freedom* – embodied through the usage of undo – has to be implemented to enable efficient and smooth interaction with computing systems. Yet, the resulting ubiquity of an *undo* functionality stands in contrast to the causality of interaction we experience in the physical world, as in the virtual world, we can revoke and reverse almost all our (inter)actions. In most cases, the reversal happens with a simple click on a button and without visible consequences on

[1] In the following, we will refer to the **human in interaction** as **actant** to differentiate from study (participant) and usability (user) contexts.

the system or the actant – as long as action and effect stay within the system, not affecting other human actants.

Without any ambition for the iconoclasm of the essential achievement behind the undo functionality, we initiate a thought experiment in this paper with the following two questions:

How could interactive technology look without undo functionality?

What are the implications of such irreversible interaction concepts?

In following upon this thought experiment, we line up with speculative [5] and critical design [6, 7] practices. Thus, we explore the *undesign* [76] of *undo*, sharing our observations, insights, and learnings, while not questioning the usability of either reversible and irreversible interactions.

In order to inform the design of irreversible interactions, we contribute the first comprehensive discussion of irreversible interactions as a topic in HCI, presenting:

(1) three **design speculations** evolving around undesigning undo,
(2) a **conceptualization** of irreversibility, helping to understand the influencing factors and properties,
(3) and three deduced **design strategies** for implementing irrerversibility in HCI systems.

We address the topic of irreversibility in the following structure. First, we provide insights from our design speculations and compare our observations with exemplar projects, which fit our understanding of irreversible interactions. Second, we present an initial conceptualization of the properties and factors that shape the qualities of irreversible interactions. Third, we contextualize our speculations, the related work, and our conceptualization and deduce *altering*, *creating*, and *destructing* as design strategies for irreversible interactions. Finally, we discuss application purposes, focusing on reflection and mindful acting, meaningful thresholds, and embedded narrative. We end our discussion with the influence of irreversibility on power and empowerment in human-computer-interaction.

2 MOTIVATION & BACKGROUND

Irreversibility is an inherent characteristic of our physical world. The second law of thermodynamics teaches us that a process is irreversible if it can not return to its initial state by following the reverse order of actions. In other words, there is a $X \longrightarrow Y$, but no $Y \longrightarrow X$ [18, 19]. The concept of irreversibility, due to its omnipresence and emergence in different facets, is deeply rooted in human thinking patterns. This is reflected, for example, in proverbs which touch on the theme of irreversible spoken words ("A spoken word cannot be taken back.") or done deeds and scarce resources ("You can't eat your cake and have it"). While in the physical realm causality and irreversibility are axiomatic properties that can only be approached with deliberation and sharpened awareness in interaction, computer scientists recognized early on that this can be transcended in the digital.

In what follows, we will first explain how irreversibility in the digital realm has been partially overcome by the undo feature. Secondly, we will touch upon how computer interfaces in the physical realm deliberately use material's inherent limitations to create specific experiences and interaction flows.

2.1 Undo: Overcoming Irreversibility in the Digital Realm

To overcome irreversibility in the digital realm, especially in the context of human involvement – with its inherent fallibility – the simple reversal of one or more actions in a computer system is one of Shneiderman's golden interface design postulates [89].

The idea of undo as an essential system's feature is older than 30 years, with many researchers to date investigating what undo is and what it should do (e.g., [4, 95, 100]). Abowd & Dix [1] discuss the difference between these two questions on undo. What undo *is* presents the system's perspective on undo. As such, undo is a function, an interface element, a feature that the system gives the actant to their disposal in order to easily revert actions. What undo *does* eludes an actant's intention to reverse to a previous state, not necessarily using the undo feature. Having a dedicated undo that enables the reversal is highly suggestive, but not necessary to carry out the undo intention.

The main purpose of undo is to recover from erroneous or mistaken actions through forward and backward error recovery [1]. In backward recovery, actants "retrace their steps and reverse the effects of past actions" [1], whereas in forward recovery they "determine a new course of action which will take them forward from their current situation toward their original goal" [1].

Another perspective on undo is to conceptualize it as an enabler of "redo". According to a system's reachability property [62], undo allows reaching some of the system's previous states. As consequence, undo and redo together form a "causal dependence" [62] – in order for a redo to exist, there must have been a previous undo. Antonymous to undo, redo is the bearer of achieving alternative future system states. Undo and redo can help "relief anxiety"[89], and as such, engage the actant in interaction surpassing error recovery (e.g., [2]), e.g., in "exploring unfamiliar options" [89].

2.2 Materials and Intentional Design Limitations in HCI

Opposite to the digital realm, irreversibility is implicitly contained in matter, with irreversible processes creating new materials or lasting changes. Referencing our surroundings physical world and its concepts can be beneficial for the user experience [63] and overall intelligibility of new technologies, as users' prior knowledge and real world experiences are taken into account [51]. For example, Reality-Based Interactions (RBI) focus on the actants' skill and awareness to bodily act in their physical and social surrounding. More recently, materials and material sciences [79] have continued to become a focus of HCI research [42], as digital content is increasingly integrated into actants' daily lives and environments [50] – with such properties of materials as permanent and non-permanent material changes being investigated. The manipulation of the surrounding matter and the resulting experience [38] is a central design approach since it puts the material qualities in relation with the actants' prior knowledge. The manipulation of objects based on their materiality [84], such as squeezing or crumpling, can be mapped to understandable actions such as distorting sound [96] or as a representative action for emotions such as anger [92]. Ephemeral user interfaces [31], with soap bubbles [93] or ice [17] as materials, embody the concept of *transiency*, by the impermanence of the materials. Edible interfaces [55, 65] elude *finality* in that the material is scarce. Thus, a causality is established that is understandable and clearly conveys the impact of actions [24, 25].

Using such materials comes implicitly with constraints, which can be conceptualized as external restrictions. However, intentional design limitations – which are self-imposed restrictions –, such as using *ephemerality* (opposed to the permanence of the digital), are increasingly gaining momentum in HCI. A variety of design limitations aim at deliberately decelerating the human-computer interaction. Design frictions [67] intentionally break the interaction flow to create awareness and thus prevent errors and potentially harmful actions. Similarly, reflective design [86] and slow technology [45] seek to promote contemplation and thoughtfulness of both one's own and others' (inter)actions, with the goal of changing or accepting one's behavior [21]. In addition, interfaces can even strive to reverse actant's expectations on their functional premises to encourage critical thinking and action [7]. Counterfunctional interfaces limit a system's expected functionality, but at the same time seek to encourage the invention of new ways of interaction [77]. Most extremely, and with the same goal as previous designs, there have been recent calls to "undesign" technology [76], ranging from inhibition to complete erasure of parts of tech's functionality.

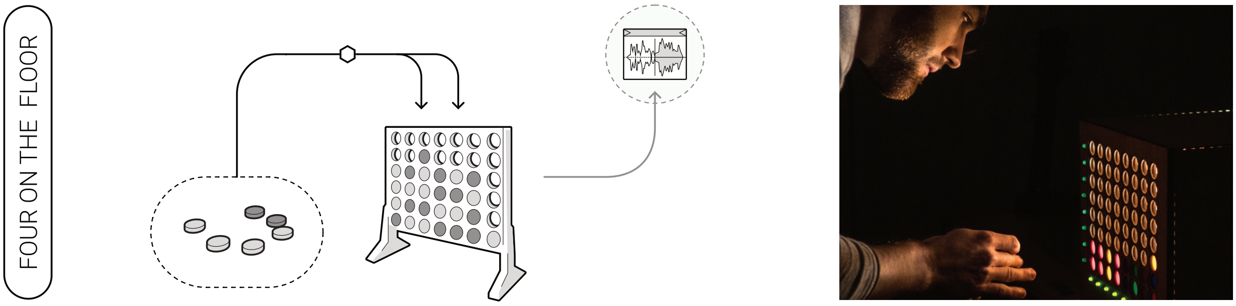

Fig. 2. Typically, music software tries to optimize actants' efficiency. If the "undo" functionality gets removed, the irreversibility of actants' actions is enforced. Consequently, actants have to change their usage patterns from trial-and-error exploration towards prospective thinking and mindful acting.

2.3 Summary and Objectives

As described before, irreversibility is a fundamental and ubiquitous principle of the physical world, which is comprehensible for the human being acting in it. In contrast, in the virtual realm, undo functionality was introduced to overcome limitations imposed by non-reversibility – now established as an enabler of interaction and exploration. With the entrance of interactive technology embedded in and interwoven with the physical world, both principles are competing with each other. In our work, we explore the undesign of undo in tangible artifacts as a dedicated system's function – that is, what if there existed no undo on the system's level per se? Hence, we rediscover and appropriate this alleged deficiency and instead amplify it as an inherent material quality and property.

In doing that, we add to the body of research on design limitations by examining and conceptualizing the conscious limitation of not having an undo, i.e, making our interaction with computing systems irreversible. In what follows, we present three design speculations that make use of irreversibility at the core of their functionality and interaction with the actant.

3 DESIGN SPECULATIONS

We present three design speculations drawn from the authors' recent research[2]. Following the research through design process and critical design methodology, we contemplate these projects to rather present "artifacts intended to be carefully crafted questions" [101] than to be formally informed design decisions. In doing so, the artifact is the materialization of the question through which we can observe and reflect on its effect on the actant. Although these projects are situated in interchangeable contexts, they share the same core principle: irreversibility in their interaction. Our goal was to explore how irreversibility shapes actants' thoughts and actions, aiming at identifying factors that influence their interaction with the system one way or another. However, we do not lay focus on empirically testing nor comparing the speculations.

For each speculation we provide an overview of the design aims and report on observations that, although difficult to quantify, we believe highlight the essential features of irreversible interactions.

3.1 Four on the Floor – Irreversibility in Production

Modern musicians are used to music production software that includes usability principles such as undo functionality to increase productivity and effectiveness by lowering the risk of potential

[2] All participants of the system evaluations agreed that their data may be used for scientific publication in anonymized form and were compensated fairly.

harmful interactions. Contrary to this, former practices such as playing and improvising live music require foresight and the consideration of the musical context in advance to successfully perform music. In that sense, music production on the computer entails an exploratory process that is much more about user freedom through trial and error and its retrospective analysis. On the other hand, playing live music requires a commitment to performed interactions, which builds primarily on prospective thinking and audiation [40].

The aim of this speculation was to explore how a production task and the related user experience change when the familiar reversibility is removed from a computing system.

3.1.1 Artifact Design. We designed the experience prototype *4 on the Floor* (cf. Fig. 2) to create a musical production interface which incorporates irreversibility in its workflow. Our design goal was to naturally include the irreversible interaction by building on a familiar interaction concept for which actants already accept irreversibility. Since step sequencers and midi loops already look like chess boards or other games, we looked for a game during which players accept that their actions can not be modified. Thus, we picked the *4 in a row* game and transferred the idea to a musical sequencer (see Fig. 2). By dropping colored discs in an eight by eight vertically suspended grid, actants build musical melodies and rhythms. The colors represent pitch or samples and the columns along the x-axis represent time increments. By throwing chips into the grid, a sequence of notes is created and stacking chips forms chords or layers sounds. This sequence is constantly repeated in a loop, as known from step sequencers. Via a webcam-based image processing approach, the chips were tracked in real time and then sent to a digital audio workstations for sound generation.

3.1.2 Observations. We confronted 20 actants (self-identified as: 11 ♀ and 9 ♂; average age: 24.2 years) in an AB testing setup with our speculative design artifact. They used the interface in two configurations in a counterbalanced order. The first configuration (A) used the irreversible interaction, whereas the second configuration (B) allowed removing particular chips at all times.

When asked about the benefits of the irreversible interaction, actants reported that they appreciated the creative aspects (n=6), the thoughtful process (n=6), the challenge (n=4), and the playful qualities (n=3). Only two actants completely rejected the concept, with one reporting frustration due to the inability to change already entered notes (ID19). A closer investigation showed that actants in favor of the irreversible process were divided into two different mindsets. Eight actants exclusively pointed towards playful or creative aspects, whereas six actants enjoyed the interface due to its challenging and thoughtful character. Further, one actant stated that "... every step had to be carefully considered and it was necessary to reflect if the previous decisions were working towards the planned results. Mistakes triggered creative reactions which was overall a lot of fun" (ID1).

Observations in the irreversible case revealed some actants to occasionally pause the interaction and take a step back, in order to get a holistic overview. Consequently, this action created a moment of rest to think about and plan upcoming interactions.

3.2 SocialShredder – Irreversibility in Providing Personal Data

When interacting on social media, whether by uploading, commenting or liking content, actants are often aware that they provide personal data to the platform. Yet, they still not having privacy concerns regarding such services – this phenomenon is called the "information privacy paradox" [57, 74]. Our hypothesis is that few know that each interaction with social media is more or less irreversible, even though it seems reversible. If an actant likes and later dislikes an image, the like may be deleted from the web interface, yet, the like-dislike interaction depicts a valuable information for companies. Further, effective data removal from trained machine learning models

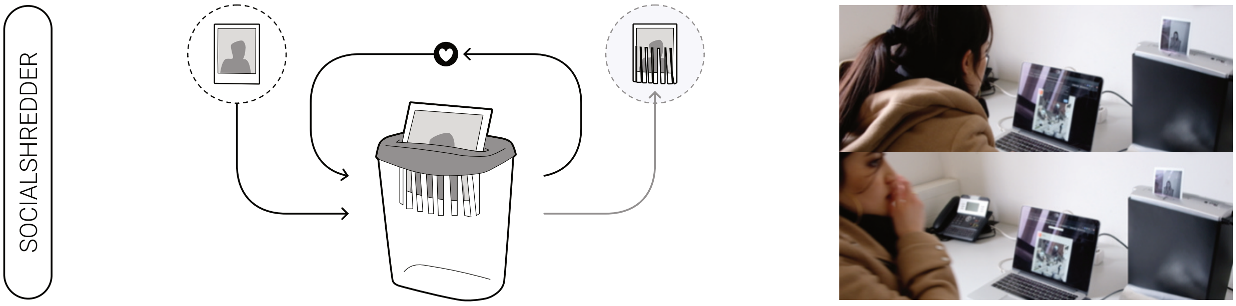

Fig. 3. The provision of data on the internet is often not fully reversible. Despite this, actants often do not adapt their usage behavior. By illustrating the irreversibility of their given data via the incremental alteration of a personal photograph, the actants adapted their behavior during our exploration and provided less likes.

is not trivial [39], if not impossible. Nonetheless, only few actants indeed change their interaction patterns on such platforms due to this knowledge.

The aim of the speculation in the context of providing personal data was to explore whether an actant's behavior changes if the irreversible nature of their interaction (with social media) is materially emphasized.

3.2.1 Artifact Design. We designed the experience prototype *SocialShredder* (cf. Fig. 3) that irreversibly alters a personal item – a Polaroid picture of the actant – whenever they like images on a mock-up social media platform. This visualizes and emphasizes the fact that the provided personal data is lost and cannot be demanded back in its entirety. Thus, we strive to achieve the following: first, interrupt the actants and shift their focus away from the virtual realm to disturb the automatized behavior pattern [52] and second, communicate via an incremental and irreversible alteration of the physical image that some of the actants' personal data has been irrevocably lost. This cause-and-effect relation is easy to conceptualize and strikingly illustrates that, once an image is liked and thus altered to ultimately destruction, it can not be restored by disliking the content. Even if this happens, the Polaroid will stay irreversibly destroyed. We built the artifact from a document shredder that was controlled by an Arduino. Via USB, the shredding action was triggered whenever a *like* was given on the mock-up platform.

3.2.2 Observations. To explore the effects of the irreversible feedback on actants' behavior, we let 16 actants (self-identified as: 9 ♀ and 7 ♂; average age: 27 years) experience the speculative artifact. They had to interact with the image feed of the mock-up social media platform where they could like the posts. The exploration incorporated two conditions: (A) with irreversible feedback, i.e., Polaroid shredding, and (B) without additional feedback.

Our observation has shown that the actants liked less images in the condition with irreversible feedback provided. Further, actants reported (1) longer contemplation on whether they should give a specific like and (2) a heightened awareness of their likes being irreversible information. When reflecting on the experience with the irreversible condition, actants stated that they were influenced by the destruction of the picture – they felt bewildered and confused by the feedback, and the majority experiencied no fun as a result of the interaction. During the interviews, we found that actants responded differently to the irreversible feedback. Some completely stopped the interaction after they realized that pushing the like button results in the Polaroid being cut. As the statement of ID5 suggests, "I only gave one like, since I found it unpleasant and terrible to destroy an image of myself", responding also to the socio-emotional meaning of the personal image. For some, this was no reason to restrain from the interaction. Yet, it did change how they

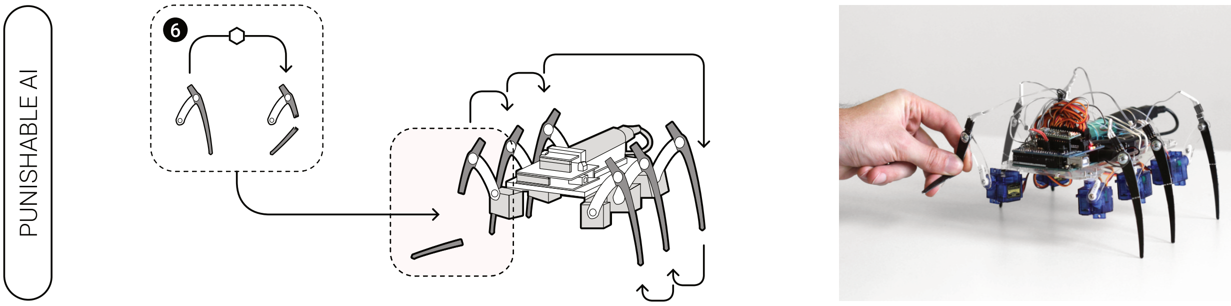

Fig. 4. Irreversibility emphasizes the effect on the system to which the feedback is directed. This is not due to the effect on the system, but to the actant's perception and interpretation. Breaking the robot's leg to inform the system must be consciously thought through. The finiteness of the system and the feedback conflicts with the need to preserve the system's functionality.

were considering more "carefully before [they] liked a picture and hoped that not too many good pictures would follow" (ID11) before giving likes. On the contrary, four actants continued giving likes, even after the image was completely shredded. As actant ID10 mentioned, the unusual quality of the interaction was somehow fascinating and motivated a further exploration of the interaction with all its consequences.

Our observations confirmed, that the shredding moved actants' attention away from the screen. While this was partly due to external stimuli, such as the loud sounding shredding action (which is attracting the attention based on basic human reflexes), actants as well followed along with the incremental shredding. Finally, some actants asked for their individual Polaroids even when completely shredded since they wanted to keep them as a memory or souvenir.

3.3 Punishable AI – Irreversibility in Interaction with Intelligent Systems

As intelligent systems continue to enter the everyday live, new design challenges are emerging. Whereas natural concepts and RBI principles are used in designing the interaction, not all usability principles are still applicable [3, 32]. Since providing feedback and fine-tuning such systems can be challenging, anthropomorphic design strategies, such as praise and scold [12], are considered to enable the interaction for non-expert actants. To accept such interactions, actants need to believe in the effect of the method. This requires their belief that (1) the machine is sufficiently intelligent to understand the meaning of and (2) is affected by the interaction.

The aim of the speculation in the context of intelligent systems was to explore how actants perceive the impact of feedback when applied with irreversible consequences.

3.3.1 Artifact Design. We implemented a walking robot – personified as an insect – to investigate whether the human perception of the consequences to a system of providing feedback (influencing the robot) changes when performed as an irreversible interaction. Here, the robot should be trained to walk a straight line. When it gets off track, the robot gets "notified". Feedback to the robot is provided first by scolding, second by a negative stimulus (bright flashlight), and last by gradually breaking the robot's legs (see Fig. 4). The breaking interaction was limited by design and could only be repeated once per leg. Implicitly, the finite character of the interaction communicates a strong impact of the interaction to the system, compared to the non-destructive modi. Several design aspects aimed to implicate the irreversible interaction, such as the fragile, long, and thin legs as well as the predetermined perforation which both indicate the breakability. Through the PCB legs, the state of the legs (interrupted traces) and touches of the actants (capacitive areas) could be sensed. While all feedback mechanisms were in fact carried out during the interaction, the learning of the system was not implemented, since we were interested in the experience during the application of the feedback and not in the feasibility of the machine learning aspects.

3.3.2 Observations. 20 actants (self-identified as: 9 ♀ and 11 ♂; average age: 26 years) participated in an exploration of the design speculation. They executed the three feedback methods (scolding, negative stimulus, breaking the leg), which represented a stringent escalation during the training. The detailed results have been published in [REMOVED FOR BLIND-REVIEW]. For that reason, we will highlight only results of interest with respect to irreversibility. As a new perspective, we add informal observations that emerged from an internal colloquium, during which we presented to and discussed the prototype with professors and senior researchers from the HCI and computer science context.

The observation and analysis revealed that the irreversibility clearly affected the actants, as they hesitated to execute the breaking action and stated to rather avoid destructive feedback. During execution, some actants responded strongly to the implemented reactions of the robot. When the robot started trembling upon touch, to depict resistance, they sighed and there were short exclamations like “Oh no ...” when they broke the leg. Due to the PCB’s flexibility, a certain force must be applied before the leg snaps. Thus, actants slowly built up the tensions until they reached the breaking point, which created a moment of anticipation. Additionally, eye contact with the instructor was sought as if they were looking for confirmation of their actions. The subsequent interviews revealed both an economic and an emotional argument against the irreversible interaction. Some actants felt empathy for the robot and thus, the interaction was perceived as cruel and discomfortable, affecting their own emotions.

During the demonstration in the colloquium, we primarily observed two behavior patterns. First, we discussed with advocates of the economic reasoning. They saw the irreversibility in conflict with maintaining the robot’s functionality. In an extreme case, one actant categorically refused to carry out this action, as he principally objects senseless destruction. Second, many experts perceived the idea as a curious provocation, contradicting established design principles. In that spirit, they rather executed the interaction for entertainment reasons. Yet, they re-visited the demonstration, at times more than once, to further engage in discussions. We interpret this as an indication for a triggered reflection process.

3.4 Summary

Within all presented speculations, actants demonstrated a clear understanding of the cause-effect relationship, that is omnipresent in the irreversible interactions – either by the finite nature of the interacting object, in conjunction with the irreversible change or by the limited access to an interaction-relevant resource. This can be explained by the basic human understanding of the physical world [51], on the basis of which the consequences of (inter)actions are extrapolated and anticipated. Thus, the actants knew that a chip thrown into the *4 on the Floor* matrix, could not be removed. Similarly, they knew when a second like is given, the image would be further altered by the *SocialShredder*. Finally, they knew that when most legs of the *Punishable AI* robot were broken, it would be unable to walk.

Whereas the causality, and the aforementioned RBI perspective, can explain actants’ understanding of irreversibility and its effect on a system, we have reason to believe that these perspectives are not fully adequate to explain why actants are affected – to the observed extent – when confronted with an irreversible interaction.

For example, we observed that irreversibility stimulated actants to contemplate about their actions (*4 on the Floor*), reminded them about action implications (*SocialShredder*), or made actants

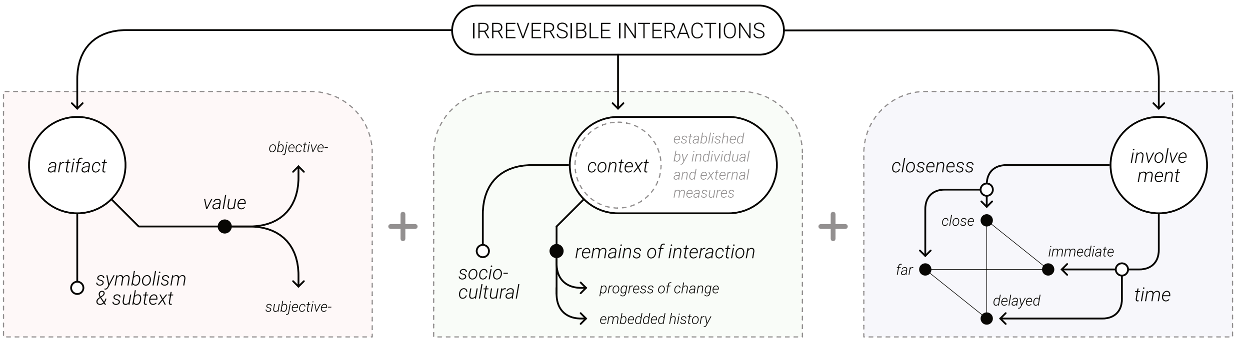

Fig. 5. We found three main properties influencing the experience during the irreversible interaction. These are artifact, context, and involvement related.

reconsider the sense of an action (e.g., breaking a leg) due to the irreversible alteration of an interactive object (*Punishable AI*).

As consequence, we want to highlight three key observations beyond the simple restrictive nature of irreversibility.

- **O1** Actants *consciously* interrupted their interaction flow when confronted with an irreversible action.
- **O2** Actants *showed interest* in the objects they irreversibly altered.
- **O3** Actants' reasoning against the application of irreversible interactions went *beyond purely rational* considerations.

Looking into the observations, we recognize that various factors shape the effect on the actant. For example, **O2** is based on the object itself, whereas **O3** poses questions about the reasoning process, among others, the personal or social context. This led us to conceptualize irreversibility, in order to appeal to the question "what factors of irreversibility contribute to the observed influence on the actant behavior?". In what follows, we suggest factors of irreversibility that differentiate an irreversible interaction from other interaction principles, as part of HCI.

4 CONCEPTUALIZING IRREVERSIBILITY

To understand the influence of irreversible (inter)actions on the experience, we consider the influencing factors that are either *unique* to, *influenced* by or *emphasized* by irreversibility. By doing so, we focus on the gap between objective measures – the artifact and interaction design – and the subjective experience. We conceptualize the experience process similar to the communication model of Shannon [87], in which a message is distorted by noise. In the context of irreversibility, the identified factors contribute to the experience as a distortion. Understanding the factors and their relationship, helps to better understand the experience of an irreversible interaction.

We deduced the following factors by comparing our speculative artifacts and exemplar HCI projects that, in our opinion, similarly include irreversibility in their designs. As result, we identified shared properties that we consider to be influential in the conceptualization of irreversible interactions and their effect on the actant. These properties (see Fig. 5) contain factors that belong to (1) the artifact, its materiality and object character, (2) the context which is established by the individual and external measures, and (3) the actants' involvement in the irreversible (inter)action itself.

4.1 Artifact-Related Factors

Both our speculations and the exemplar projects, make use of diverse materials and objects. Two main factors, the artifacts' *value* and *symbolism*, can be considered as explicit design decisions.

4.1.1 Value. Irreversibility in our context directly involves the interactive artifact with its entire materiality, sometimes with permanent consequences that diminish its value. The artifact's value can depict two different things. First, the *objective value*, i.e., an economical value based on supply and demand or on a societal agreement. This differs a Fabergé egg from a hen's egg, or an ordinary piece of paper from a money bill. Second, the *subjective value* which is either based on the individual's subjective perception, emotional attachment and past experiences, as well as on cultural considerations such as moral and ethical principles.

Objective Value - In the case of *Punishable AI*, the robot, as a technological device, gets attributed a relatively high objective value. This value influences the economical considerations when interacting and consciously breaking the robot apart. The objective value, attributed to complex devices, depicts a threshold which has to be actively crossed when applying the irreversible interaction.

Differently, *Destructive Games* by Eickhoff et al. [34] uses the objective value of money to increase the interaction stakes. Here, two players are cutting apart a money bill in a laser-cutter during the game play. Replacing money with paper would lower the stakes, the implied risk, and thus the commitment which positively affects the excitement. In both cases, a typically thoughtless interaction becomes a conscious choice due to the artifacts' objective value.

Without value the same action becomes trivial such as breaking a toothpick or tearing apart a napkin. In this way, incense chips are used in interfaces for spiritual interactions [99]. Here, the irreversible material change determines the time-span of the experience, acting as replaceable resource and therefore neither creates a threshold nor a high stake interaction.

Subjective Value - In contrast, the portraits used in the *SocialShredder* experiment or the handcrafted items in *Scotty* by Mueller et al. [71] hold a greater subjective than objective value. In both cases, a unique item gets destroyed during the interaction. In the case of *Scotty*, this object is later recreated via a 3D printer when sent to a friend. The destruction of the original has a great importance, as the uniqueness and thus the subjective value is preserved. In the same way, the Polaroid used in the *SocialShredder* bears an individual subjective value for every single actant, based on its uniqueness (non-digital) and the personal motif, which even can outlast the object's destruction (**O2**). This perception of subjective value is as well used in the music-box prototype *MuRedder* [56], which builds on the subjective experience of music. In *MuRedder*, simple paper tokens, representing songs, are shredded to be played back. Whereas, the token only bears a low objective value, actants were consciously planning the time and place of listening the music piece to be able to actively listen and value their favorite music.

In addition to the personal attachment towards cherished objects, subjective values can also reflect societal norms and principles. As reflected in the statements of some *Punishable AI* participants, they revealed strong principles they applied to reflect on the destructive interaction (**O3**). This is comparable to Bartneck et al.'s [8] assumption that the perceived intelligence of a robot influences the willingness to destroy it, such as there is a lower social acceptance regarding the killing of intelligent animals (cf. mosquito vs. primate). Such considerations can include (a) ethical principles, (b) moral norms (e.g. the value of life, which is often used as a constitutional principle [9]), or (c) societal standards.

4.1.2 Symbolism & Subtext. The reference made in the design of an interactive artifact can create a decodable subtext based on, e.g., the collective memory [44] of a society. When we compare *4* *on the Floor* and *Punishable AI*, we see that the design informing objects influence the perception of the irreversible interaction. There is a playful reference in the *4 on the Floor* project to stimulate a free, uncomplicated, and exploratory interaction. Whereas, the zoomorphic design as a symbolic representation of a living organism, stimulates the need to preserve and maintain the artifact. Further, breaking a leg creates a different subtext than smashing a robot with a hammer in pieces [8]. One could argue that the destruction itself is already connoted negatively and primarily defines the subtext, however many everyday activities create joyful experiences through destruction. Unwrapping a present by ripping the paper wrap apart in sheer anticipation creates a different emotion than receiving the present without surprise and symbolic stimulation. Just like the incremental destruction of a flower when playing "He/She loves me ... he/she loves me not ..." can create amorous excitement, since the actions cannot be reversed and the outcome cannot be predicted. Further, many people enjoy popping bubbles of a bubble-wrap, which can even have a calming and stress-releasing effect on the performer [28]. So part of the experience is based on the choice of object and material, what associations they trigger, and what interactions with such an artifact are perceived as natural and fitting.

4.2 Actant-Dependent Context

Values, symbolism and subtext depend to a great degree on the interpreting person and their societal context [11]. Contemplating the design process as the creation of meaning is not possible without considering the individual using the artifact, thus creating an own context in which design and interaction are interpreted. The context created is partly personal as well as socio-cultural. When an individual is confronted with an irreversible interaction, which is generically about permanent change or a transformation, we can objectively describe the change such as "ice transforms into water" but the perception of *melting ice cubes*, *a melting ice sculpture* or *the melting of the polar caps* depends on the context that first is established by the individual or the belonging society.

Remains - If we take a look at the *Punishable AI* and the *SocialShredder* projects, the state in which the artifact remains after the interaction has – via the irreversible alteration – some visible history embedded. We can see how many legs already have been broken or how much of the picture has already been shredded. Comparable to research on traces of use in HCI to embed information [82, 83] and affordances [48] into interactive artifacts, irreversible interaction artifacts implicitly do the same. For example, the project *PlantDisplay* [58] communicates actant's social interaction with others via the adapted watering and consequently encodes the actants' interaction in the health of the plant.

In fact, permanent changes that tell a story are incorporated in many cultural practices. For example, everyday scars allow people to get in touch with others, by comparing them, telling stories based on them, and via these empathetically relate to others. In that sense *SocialShredder* participants developed an interest in the remains of their Polaroid pictures since they embed a story to be told (**O2**).

Socio-cultural Context - To fully understand the meaning of an irreversible interaction, one has to consider the socio-cultural context, e.g., cultural practice or history. Take, for example, human scars. While in many western societies facial scars are today seen as an imperfection, in the cultural practice of scarification [37] scars are perceived with a spiritual or tribal meaning. The same goes for the so called "Schmiss"[13] (facial dueling scar) which, in the early 20th century, Germans perceived as a badge of honor, but bewildered foreigners.

In HCI, the projects *InScene* [54] and *SenseCenser* [99] both make use of the irreversible act of burning incense chips during the usage of their interfaces. Burning incense is common in the spiritual context, which is shaping the perception of this action. Yet, burning other materials or in another context creates a different meaning and experience. Whereas burning incense creates a fragrant smoke, which is connoted to be relaxing, meditative, and used consciously, lighting up a gas stove will be perceived as functional, as it is pragmatically used in the everyday processing of food.

On the contrary, burning books (even if seemingly equivalent to the burning of other matter) is perceived as a much "heavier" act. This is due to the history of censorship, in which burning books symbolized burning *knowledge* – contrary to the books' intended function to collect, contain, and preserve information. Yet, this historical link was established only recently. Beforehand, in ancient cultures, there was a predominant "intimate connection between destruction, burning and purification" [47].

4.3 Actant's Involvement

The last factor, is the interface's way to involve the actant in the irreversible process. We identified that actants take roles, based on their involvement in the interaction, which, in turn, shapes their experience. Illustrated by the art installation *Helena & El Pescador* [33] – in which visitors were confronted with a set of blenders, each containing one living goldfish – the visitors either were *actors*, actively blending the fish, *spectators*, waiting on the sideline for someone to blend, or *moralizers*, who went by and built their opinion[3]. Either way we actively participate, but the way we participate shapes the experience. With this example in mind, we identify two dimensions of the involvement. First, how *"close"* our action is coupled to its consequence – is there a proxy between the interacting artifact and the actant? Second, how much *"time"* separates the consequence from the cause of the interaction – is there a delay or is the consequence immediate? The non-existence of a proxy and of a delay contribute to what we call a stronger involvement since the "distance" between the actant and the system is reduced. In other words, there is a direct cause-effect relationship visible. While both dimensions are continuous, out of simplicity we consider four different *closeness-time* combinations of actants' involvement: (1) close & immediate, (2) far & immediate, (3) close & delayed, and (4) far & delayed.

Close & Immediate - The closest way we can apply an interaction is probably by doing it with bare hands, directly on the artifact, in real time. In that sense, *Punishable AI*, *To kill a mockingbird robot*[8], or *Obscura 1C* [78] directly involve the actant without a separating proxy. The actant thus becomes the active performer, breaking the interactive device and in this role takes full responsibility and perceives the full agency regarding the interaction.

Far & Immediate - When adding proxies between the action and the effect the irreversible interaction has, the distance between cause and effect is enlarged – the involvement is reduced. Examples for this are *SocialShredder*, *DESU 100* [80], *Destructive Games* [34], or *Scotty* [71]. Here, a button press evokes the irreversible alteration – instead of a direct destruction. This indirect relation reduces the involvement and can change the perception from being the actor towards being in a spectator role.

Far & Delayed - Increasing the time between the cause and the effect of an interaction will let the actant perceive less responsibility for the action, taking a rather spectator role. In *PlantDisplay* [58], the actant's social contacts lead to watering the plant, thus happening in a different context. In that sense, the plant is a visualization of the actant's behavior only indirectly affected by it. Furthermore, the delay occurring between the plant being not watered and the plant drying out increases the distance between cause and effect.

Close & Delayed - We could not identify related work that presents an actant involvement, which uses a direct cause in conjunction with a delayed effect. Still, an example from human-robot interaction can illustrate a direct cause and delayed effect. If we were to physically interact with

[3] https://artelectronicmedia.com/en/artwork/helena-by-marco-evaristti/

the robot by, e.g., punching it, we might get confronted with the consequences later in form of an, e.g., "bruise" which develops over time.

4.4 Summary

We outlined various influencing factors on the actant experience when performing irreversible interactions. These factors include, the artifact's value and symbolism, actant's personal and socio-cultural context, and actant's involvement in the irreversible change. As designers we can deliberately use and functionalize them to influence the user experience as shown in the observations **O1-O3**.

Accordingly, we can fine-tune these factors in an artifact's design and the associated irreversible interaction. Measures designers can take include the adaption of the objects objective or subjective value, the contradiction or capitalization of the socio-cultural interaction context, or the purposeful degree of actant involvement.

While the factors present a convenient way to shape irreversible interactions one way or another, the final experience is a result of the complex interplay of all introduced factors. As stated by McCarthy and Wright "any pragmatically useful analysis of artifacts is inseparable from an analysis of the values and experiences of those who use them or feel their effects", thus it is important that these factors are not considered isolated from each other since they form a "complex web of meaning relations" which amplifies itself so that it emerges to something larger than the sum of its parts [66]. This essentially reflects the understanding of interactive systems in terms of Actor-network Theory (ANT), which includes "non-material entities, such as policies, laws or societal norms" [35] and acknowledges their influence in the network of actants.

5 DESIGN STRATEGIES

Reflecting upon our design speculations (cf. Fig. 6), we have used irreversibility in three ways: (1) in *alteration*, (2) in *creation*, and (3) in *destruction* of a physical computing system. On a more general note, these approaches differ in the motivation and extent of use of irreversibility. More specifically, they encapsulate distinct characteristics of the aforementioned conceptualization. We shaped the general and specific focus through our designs, with each speculation embodying one way of approaching irreversibility in design. Following, we present these approaches as derived design strategies, suggesting how irreversibility might be incorporated into system design.

Alteration lies at the core of every irreversible interaction, as per definition, it is matter that changes without the possibility of revoking to its initial state. As such, alteration represents a middle ground between the extremes of *creation* and *destruction* towards which an irreversible interaction may gradually move. The direction of the movement depends on the value and functionality of the object, that is, the material under change. In case *added value* is being produced, the process becomes a process of creation. Otherwise, if *existing value* is being nulled, it turns into destruction.

In our speculations, we observed that the design strategies provoke more reflective and thoughtful engagement (**O1**) – regardless of the included factors. In the *SocialShredder* project, the actant's own image is altered with each like on a social media platform. Although finally cut in pieces, the image still preserved its subjective value of a photograph that captures a moment in space and time. In other words, the actant might still recompose the shredded remains (**O2**), distinguishing this process from destruction. By visualizing their interaction, actants felt provoked to more deeply think of the consequences of a superficially harmless interaction. Furthermore, the number of shreds could provide narrative on how many likes have been given, with additional information potentially enriching the narrative. For example, information on when the shred happened, with varying periods between, might point to actant's hesitation to act towards the end. In *SocialShredder*, the actant indirectly (i.e., far) and gradually decreased the photographs value. The effect of shredding

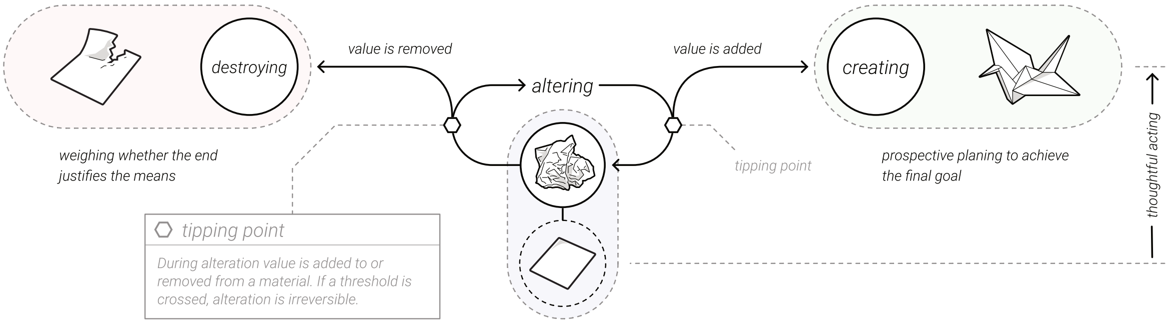

Fig. 6. Altering a material can either end in creation or destruction, depending on whether value is added or nulled. Illustrated using paper, a sheet can be torn in destruction, crumpled in alteration, and folded into an origami creation. In destruction, the paper looses its functionality and value. In crumbling and folding, the creases are permanent, but the paper remains functional. Additionally, value is gained in creation. Along that continuum, if a certain threshold is crossed, alteration irreversibly tips. The carefulness of alteration will in this case highly depend on the value of the used material – it is not the same for a blank piece or a 100€ bill.

was increasingly visible by the end, moving the tipping point rather far – in space and time – from the actant.

The tipping point presents, on the continuum of actant's engagement in irreversible interaction (i.e., the lower curve in Figure 6), a certain threshold at which the value substantially changes, either decreases to void or exceeds its initial value. At these points, the heightened awareness about the interaction turns into more profound, even existential, considerations (**O3**). The greater the value changes in both directions, the higher the thoughtfulness of acting.

In **creation**, the actant's imagination is challenged towards the end result by continual re-examination of the steps and work-arounds that lead to a potentially surprising result. Although reversibility and undo are said to promote creativity and exploration, we observed in *4 on the Floor* that actants were, by trial-and-error, rather handling towards a premeditated goal. Actants created the music piece again only by proxy (i.e, by throwing chips into the raster), the change implied was delayed (offset between playback position and position of change). Each step within the irreversibility condition required brain work and imagination, as the output of the step had to be played in mind upfront. If we think of current, everyday digital technologies, we have deprived ourselves of the right to be bored, thus abolishing moments of imagination, contemplation, and reflection. If we are unable to stop (mindlessly) using technology, can we restore creativity by implementing irreversibility within our interaction with such everyday technology?

In **destruction**, the end result is clear – to diminish the value of an object – but the reflection is rather contained in the re-examination of the meaning and sense of the act of destruction itself. In other words, with each step, actants actively weigh whether the end result justifies the means (**O1**). The threshold marks the point at which there is no going back – at which the value is irreparably lost. In *Punishable AI*, actants could directly break the robot's legs with immediate effect – the tipping point is passed when the robot could no longer move and thus lost its functionality.

While we identified three design strategies, we do not claim completeness. These strategies can motivate and guide the design of interfaces that use irreversible interactions to create embodied and experiential interactions. Additionally, the strategies and their properties are not exclusive. For example, there is a thin line between alteration and destruction in the *SocialShredder*. It even makes sense to combine the strategies. For example, in WabiSabi [98] an object is first destroyed, but then its remains are carefully being glued together with gold. This in turn, adds value to the initial object.

6 DISCUSSION

While at first glance our design approach seems fundamentally contrary to decades of HCI research [73], we found that the intentional appropriation of irreversibility can stimulate actant behavior which joins in with current research trends. This accentuates the interest in designing HCI systems in a way to address qualities that focus more on actants' well-being [46, 91], system sustainability [29, 90] or meaning [68, 69] than to create systems, which are only about accuracy, speed or usability. In that sense, our discussion breaks down to three application purposes – on the actant and the interacting system respectively – for employing irreversibility in design. We discuss these application purposes against current HCI research.

6.1 Stimulate Reflection and "Mindful" Acting

Our observations with our designs, together with studying exemplar HCI projects, showed irreversibility to break actants' mindless *interaction flow* [20, 23, 30]. In turn, actants reflect on the implications of their actions and thus on the actions themselves. This is of interest when modern technologies take over the thoughtful use and consumption of technologies, media content or social experiences and instead turn these into addicting application models [70, 88], which with the help of dark patterns [41] coerce, steer, or deceive actants. In this respect, we see the potential of irreversibility to actually create "reflective" technologies that incorporate implicit "mindful" actions helping us being present during our interaction [81], instead of designing technologies which explicitly teach us how to be mindful [26]. This can be considered to follow along with the work of Niedderer [72] on performative objects. While these achieve "mindfulness as caused by a modification of function" [72], irreversible interactions achieve mindfulness as caused by the modification of the typically reversible interaction consequence – by employing an actual consequence compared to a state of no consequence at all. Thus, in both cases the actions become focus of the reflection, forcing the actants to pause their automatized *interaction flow* and focus on what is actually done in the situation.

6.2 Create Meaningful Threshold

While the aspect of mindful acting is in general about a constant change of actant behavior, irreversible interactions can as well function as intended thresholds the actants have to cross actively in order to selectively trigger conscious decision making in the context of high-stake interactions. This function of irreversible interactions is comparable to research about microboundaries [22] that make use of design elements interrupting an interaction flow to hinder the actant to unconsciously make momentous decisions. These design frictions [67] take on the functionality to stop our action and remind us in the scope of the action to be performed. While the unlimitedness of virtual systems implies "there are no restrictions", the causality of the physical world tells us "everything you do has irreversible consequences". Thus, breaking a robot in pieces to prevent its information being passed onto other entities [8] conveys this message in total clarity, whereas confirming the deletion of all data via, e.g., an app is intransparent and consequences are not comprehensible from the outside [60]. In this regard, pushing a button to confirm an action is meaningless in itself since it is the same for saving a file, sending an e-mail, or deleting the hard-drive. Irreversible interactions, however, can emphasize the causality and the action's finite character, thus creating a meaningful [27] experience.

6.3 Embed Narrative

While we previously focused on how irreversibility shapes the way we interact and think, irreversibility also changes the artifact itself. This is interesting since people naturally develop an attachment to regularly used objects, which can be perceived as "evocative objects", that "carry memories, generate identities and provoke new ideas" [16]. When they get used and the use is reflected within them, they transform from the arbitrary to the personal [14, 97], creating subjective value. Basically, the alteration of the materiality [84], such as crumpling as an illustrative action, embeds a story into the material. This shows the previous interaction and implies stories about the actant's behavior. When we contemplate how this embedded narrative benefits HCI, we see connecting points in the literature. Such narrative aspects are used in board games to individualize the playing experience, which is hard to replicate within digital equivalents [64]. The meaningful change of a systems could function in Human-Robot Interaction (HRI) to create designs that show the temporal development and thus stimulate an empathetic connection based on shared memories and stories [61]. Such a relation could also positively affect the consume-oriented society (invention & disposal) towards more sustainability (renewal & reuse) [10]. If we perceive a strong connection with objects, they might be worth preserving, repairing, and keeping instead of instantly replacing. In that regard, the *wabi-sabi* aesthetic and the *Kintsugi* practice of repair value the imperfections of objects. By applying them to design, a deep relationship between actant and product can be created [94]. Technology enhanced *Kintsugi* objects have been explored to facilitate more human-to-human or human-to-self connection [15], explored pivotal interaction and the value of transformation of objects [49], and were used to preserve interactive objects [75]. Expanding on this idea, irreversible interactions show the potential to "design for long-term interaction through conscious use of impermanent materials" [98] and thus to provoke the conscious engagement and empathetic relation with technology.

6.4 Shaping the Human-Technology Relation

As explained, irreversible interactions present diverse applicability in the interface design. Yet, at their core, they share a unifying characteristic which is the question of how the human-technology relation is affected by the introduction of irreversibility. What we observed was the increased influence of the system on the human: The flow of interaction was interrupted, actions were carefully considered, and reflection was stimulated. Compared to non-irreversible interfaces, the influence of the system on the human was emphasized in its active role. Following Actor Network Theory (ANT) [35], both actors – the human and the machine – are active, since they have their own goals and activities [59]. The human who wants to achieve an objective through the system and the system which tries to enforce behavior on the human. Here, also the non-use as a consequence of a system's design [36] is an active influence.

Through the use of irreversibility the technological artifacts gain agency over the human actants. This gain in agency can be interpreted as power which is enacted between the system and the human [53]. While this power can be utilized positively as described earlier ("mindful" acting, meaningful threshold, narrative), it is important to be aware of the negative possibilities as well. If irreversibility, e.g., restricts accessibility due to financial capabilities the intended objectives of this exploration do no longer apply. However, if implemented consciously, irreversible interactions present the opportunity to disclose already existing power relations such as in the case of social media interaction and implicit data collection. While still agency and thus power of the system over the human actant is created, we can conversely interpret the resulting awareness of the actant as an enabler of empowerment [85]. Thus, irreversibility not inevitably leads to "giving away" power, but can, in itself, be empowering.

7 CONCLUSION

We started this paper as a thought experiment, asking ourselves, "How could interactive technology look like without undo functionality?" and "What are the implications of such irreversible interaction concepts?". Building on these questions, we executed three design speculations focusing on the exploration of irreversibility in the context of UX design of physical computing systems. These explorations led us to the realization that, with designing for irreversibility, the design must be as concerned with the experiencing actant as it is with the irreversible action and the artifact itself. Although this is true for any interactive system, we see it as even more important for the design of systems with irreversible interactions.

Whereas other research works strive for goals such as the effectiveness of their systems, our goals lie within the actants themselves. While the included irreversibility does not achieve faster usage or less errors, it ultimately lines up with the question what we as actants expect from future technologies. Current expectations, such as that technology supports our health, well-being, and meaning in life, can only be achieved if we change the way we interact and consume technology and media lastingly. One important step towards that goal is to design for self-reflection, meaningful acting, and a sustainable relationship with technology.

Looking into the near future, we can anticipate that certain technologies will demand mindful design considerations to make actants aware of the underlying irreversibility, which actants face during interaction. New forms of technologies are emerging, that incorporate irreversibility and which underlying operational processes and policies are hard to comprehend for an average actant. This includes technologies such as, for example, block-chain, urban robots or fully autonomous vehicles. In case of the latter, irreversibility in interaction can have fatal consequences for the human in the loop. Our learning and insights, even if based on thought and idea-provoking *critical designs*, can inform future technologies that infuse a sense of *conscious presence* for certain interactions which otherwise might blur in with the background noise of the other media elements surrounding us.

However, user interfaces, interaction vocabulary and familiar mental models are not defined for these domains and have yet to be established for these technologies. Consequently, current actants' experiences remain cloudy and ambiguous. As the past tells us it can be limiting, unsuccessful and lead to bad user experiences if familiar interaction paradigms for one domain (e.g. smartphones, PCs) are simply copy-and-pasted to novel technology forms. Yet, these forms of computing systems (i.e., purely virtual) and interactions (e.g., touch) could make use of irreversible interactions too. Currently, virtual systems incorporate almost always the same interaction (i.e., a simple button click) for a whole plethora of actions – the message of the "weight" of interaction is thus getting lost (sending a casual email to a friend vs. sending a super-critical email to the employer). Our work could thus spark discussion and reflection of whether, and how, irreversible interaction might be transferred to virtual systems, which are missing the richness of materials.

We would like to open and broaden the discourse to other persisting issues and topics in our world. These could, for example, include eco-challenges such as the *disposable device economy* in the IoT segment, strong shifts in society / *ethical HCI* aspects and discussions on regulation vs. non-regulation where we suspect that irreversible interactions could be used as a conscious design element within HCI. Our provided designs and reflections should thereby be considered as *provocative and speculative* stimuli aimed at a critical discourse about fundamental future goals we, as HCI researchers, strive for and help us defining a collective future HCI vision together.

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Eidesstattliche Versicherung

(Siehe Promotionsordnung vom 12.07.11, § 8, Abs. 2 Pkt. 5)

Hiermit erkläre ich an Eidesstatt, dass die Dissertation von mir selbstständig und ohne unerlaubte Beihilfe angefertigt wurde.

München, den 13. September 2021

Beat Johann Baptist Roßmy