Diffraction-in-action: Designerly Explorations of Agential Realism Through Lived Data

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ABSTRACT

Recent design research has shown an interest in diffraction and agential realism, which promise to offer generative alternatives when designing with data that resist treating data as objective or neutral. We explore engaging diffractively with 'lived data' to surface felt and prospective aspects of data as it is entangled in everyday lives of designers. This paper presents five biodata-based case studies demonstrating how design researchers can create knowledge about human bodies and behaviors via strategies that allow them to engage data diffractively. These studies suggest that designers can find insights for designing with data as it is lived by working with it in a slow, open-ended fashion that leaves room for messiness and time for discovering difference. Finally, we discuss the role of ambiguous, open-ended data interpretations to help surface different meanings and entanglements of data in everyday lives.

CCS CONCEPTS

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

KEYWORDS

Biodata, material, bodies, data, collaboration, empathy, being-with, more-than-human, design, design research

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1 INTRODUCTION

This paper draws on and extends literature that critically engages with the so called "commodity fiction" [45] of data: the belief that data in a "raw" form is out there available to be collected independently of its origins, context, and temporal history. Instead, we build on the growing body of design research that shows that data is neither immaterial, nor finished, but is instead coproduced by many entangled factors including people, context, and the particular sensors, analysis, and display techniques employed. Along these lines, much design research engages diffraction drawing from Barad and Haraway [5, 6, 44, 48, 49] as an approach "attuned to the entanglement of the apparatuses of production" [6, p. 29-30]. Like Haraway, Barad uses diffraction as a metaphor and broader concept for describing the methodological approach that uses reading insights through one another, aiming to attend to and respond to the details and specificities of relations of difference and how they matter. As examples of its recent uptake in design research, diffraction à la Barad 'inspired' Devendorf et al.'s diffractive analysis of design memoirs [25], 'guided' (alongside other theories) the tendential approach of Pierce's conceptualization of frictional design [88], and was 'valuable as a concept and a process' for Homewood et al. in tracing conceptions of the body in HCI [58]. Yet, particularly for reworking engagements with data, how does diffraction practically play out in the process of design research? This paper articulates examples of *diffraction-in-action*, ways that theory from Barad practically took shape in a set of case studies of design research projects that together aim to move away from the "commodity fiction" [45] of data to explore critical alternatives. Recognizing the often fraught relationship between more general theory and the 'ultimate particular' of design [104]), we do not aim to instrumentalize Barad's theory nor provide 'how to' instructions for engaging it. Rather, we illustrate particular examples of ways that diffraction, and Barad's underlying theory of *agential realism*, can come into play in selected design research projects. This theory "refuses the representationalist fixation on words and things and the problematic of the nature of their relationship, advocating instead a relationality between specific material (re)configurations of the world through which boundaries, properties, and meanings are differentially enacted (...) and specific material phenomena" [6, p. 139]

The selected design research projects focus on a subset of data referred to as *biodata*, data about people's bodies, behaviors, and more controversially, their thoughts and feelings. With biodata, there is a need to go beyond the "commodity fiction" of data to support a richer sense of embodiment, not impose external normative categories, avoid commodifying people's lived experiences into abstract data forms. We focus our analysis on design projects enrolling biodata because in the process of collecting and working with biodata, designers often have particular insight into the "the entanglement of the apparatuses of production" [6, p. 29-30], particular social and embodied experiences of trying out sensors, accumulating data, and scaffolding interpretations and insights that might be distilled from emergent data. Even as data gains its analytical power through abstraction and comparison against other data points over time [92], designers working with biodata especially can have tangible experiences of the entangled phenomena 'beyond' the abstraction of biodata. For example, in designing an artifact working with heart rate biodata, a designer might try on and informally experiment with the heart rate sensor to gain a rough intuition for how the sensor works and how the biodata produced by it 'point back' to lived experiences, such as feeling happily excited or out of breath walking uphill. Agential realism can help designers working with biodata attend to ways that people's bodies, and the biodata that stems from their bodies, are caught up in ongoing phenomena of lived experiences.

We offer designing (with) *lived data*, after Kaziunas et al.'s notion of data as "a central and relational part of being in the world" [69, p.53], as one approach to *diffractively* engaging with data, or engaging and attending to difference rather than expecting data to reflect reality in a straightforward, representational way [92]. Five case studies are presented where data was lived throughout the design process, highlighting the ways in which this approach has helped address design issues and contribute to an understanding of possibilities and limitations of different kinds of data. By analyzing these cases, we distill design principles: (1) engaging with data should be seen as an open-ended, not predefined process, in which the design researcher should resist the impulse for actionable insight from day one, (2) engage in a slow and long-term process where one should resist the impulse for efficiency and fast results. This is important in order to surface, articulate, and explore practices around data, (3) hold space for messiness combined with a careful use of ambiguity in this process, as a way to scaffold multiple interpretations and possibilities for being lived within different practices. We illustrate how, for research centred on diffractively engaging data, enmeshed in everyday life settings, these design tactics can be fruitful in defining novel problems, articulating, and bringing together interests from different actors, surfacing conflicting needs and proposing novel solutions—all important forms of design research [117].

We practically illustrate how diffractively engaging with biodata, or designing (with) data as it is lived, helps designers attend to the many factors and subjective decisions inherent to data, moving away from a representationalist frame of working with data, surfacing instead how data production both affects and depends on the world that is entangled with, and therefore fostering more rigorous, careful engagements with data more broadly.

2 BACKGROUND

In the classic informatics definition, "data" is a basic discrete set of measurements or sensor stimuli [92]. While this paper focuses especially on biodata, data produced from human bodies and behaviours, from the traces we leave in the digital infrastructures to biodata collected from wearable sensors, data is fundamental to HCI. In domains as pervasive as cyber-physical systems [73, 115] to digital health [15, 97], or in contexts as varied as factories [52], cities [79], or our homes [53, 75], we increasingly rely on data and algorithmic systems mediating how humans relate to government institutions [66], commercial actors [101], entertainment providers [47], employers [74] and even to one another [32, 70]. Indeed, most services provided to us by private and public actors in our everyday lives increasingly build on human-generated data to provide ever-more personalized user experiences [47, 101]. These developments have yet to be fully taken into account by design researchers, with Comber and colleagues identifying the emergence of a new paradigm for HCI, which they call post-interaction [22]: "while the third wave sought to design computing systems for interaction, the fourth wave is more concerned with designing interaction for and with computing — data mining, analytics, advertising". In the post-interaction world, the focus on using digital services is less about direct interaction with them, and more about the implicit background services that are enabled by them, leading some to identify a crisis on how to design for a new, data-rich world where humans and machines are increasingly entangled [22, 39, 60]. This paper tackles these concerns by starting from the concept of data as a basic material of computation, but rather than taking it as a given, we problematize it as an object of design: that it can be designed with, as well as designed.

2.1 Data as a Design Material

As Dourish describes in the "The Stuff of Bits" [28], data is inextricably connected to the physical and material arrangements that support it, from the physicality of server infrastructures and fiber optics, to sensing mechanisms, and when it comes to data about humans, their fleshly bodies. Feinberg [36] articulates the production of data as the result of design decisions at three different levels: 1) conceptual infrastructure, which determines forms of measurement and scale (e.g. counting the average of heart beats in a minute as a form of understanding cardiac activity), 2) collection processes, which implement the conceptual infrastructure (e.g. an electrocardiograms, or acoustic sensors to capture heart activity), and 3) aggregation processes, which make use of a certain standard, such as time scale or a geographical unit, to integrate many individual collection acts. Rather than being neutral, each decision made, even before "raw" data is collected, enables certain possibilities for action and constrains others, making some things visible and others invisible [20]. For example, when we pick up a sensor such as heart rate chest band, we are making use of decades of research around heart signals, ways of stabilizing, standardizing and representing heart rate, and years of domesticating these technologies in healthcare, gyms and fitness centres, associating heart rate zones with exercise goals, and ideas of normality [86]. When we design with sensing mechanisms, not only are we inheriting a plethora of design decisions made for them, possibly made for quite different settings than the ones we are designing for, but we may also be creating new ways of representing that data or coupling it to actuation that will be adopted in different settings and situations we may not foresee.

In the last decade, design researchers have started taking steps in approaching and refining data as a design material [32, 36, 40, 100, 109, 114], either by designing with data towards developing specific products [83], adopting a critical stance aimed at showing alternative ways of designing with data [61, 62], or exploring how to quantify and display different forms of bodily expressions, such as laughter [93]. In foundational work, Manzini [78] argues that novel materials should entail significant changes on how designers work with them, requiring an experiential understanding of what they enable. In HCI, this perspective has been adopted in the approach of novel materials, such as computational composites, which combine physical materials with interactivity [110], or even so called "immaterial materials" [8], such as algorithms or electrical signals, by exposing the material infrastructures they depend on. For example, Belenguer and colleagues [8] approach wireless signals as a tangible and accessible design material by exposing characteristics of the signals such as how signal strength is affected by the environment and the human body [107]. Data can be considered as a relatively novel material for design, and design research is still exploring ways of working with data. Our paper investigates diffractive engagements with data as one possible approach to working with data as a novel design material.

Data is increasingly used as a material to design products and services. In recent years, data-driven design has come to refer mostly to systems that depend on advanced analytical methods such as machine learning [116] and other forms of AI [94], often relying on large quantities of data [97]. An increasingly recognized area of concern with data-driven design is how data produces reductive models of reality, how and to what extent these models can provide "useful" insights (useful to whom and by what values or ideology?), and how these models can sometimes lead to harmful outcomes [2]. Motivated by these concerns, the scope of our work focuses on investigating design practices that make use of biodata to shape the direction of design processes. As related examples, data has shaped design processes for personalized shoes [83], and data-enabled design approaches [14] have informed the design of cars [84], wheelchairs[16], and health services [18]. Bogers and colleagues propose data-driven design as a reflective conversation with data [13]. Our work investigates the potential of *diffraction* to assist designers in approaching how data is entangled with the world.

We draw from work conceptualizing data as a thing that itself can be designed [36]. Pine and Liboiron [89] describe "charismatic data", where experts intentionally link quantitative measurement to qualitative action. In other words, data can be specifically designed to facilitate action. They provide examples of collecting and leveraging data to reduce maternal mortality and to protect drinking water. Activists also use data, for example to make human-rights violations visible [3]. D'Ignazio and Klein argue in *Data Feminism* that "differentials of power can be challenged and changed using data" [26]. In summary, not only can data be designed—and specifically designed to address important issues—the design decisions behind data are an important, ethically impactful concern of design researchers, as they can hold the key to alternative ways of designing, particularly novel ways that consider the effects that data has in the social world. Towards this end, we investigate how diffraction can help design data while attending to data's ethical implications.

2.2 Agential Realism: Moving Beyond Representation when Designing with Data

Growing interest in HCI draws from Barad's theory of *agential realism* [6, 7], to diffractively rethink measurement, data, and interaction design as *intra-actions* across *agential cuts* [7] in ongoing phenomena. Barad's theory may offer potential to re-imagine radically alternative possibilities for interaction design and data, but theory does not readily port to design [41], and more work is needed to understand avenues by which Barad's theory can be engaged by design researchers working with data. Although there is an emergence of design research drawing from agential realism [61], there are not yet concrete suggestions or illustrations of how to take this approach when designing with biodata.

Agential realism offers an alternative to representationalism [6]. For Barad, data is not a measurement of an external world, or a representation of a thing that exists independently of the act of measuring; instead, it is produced by instruments— the instruments are part of an apparatus—entangled with the world. It is in the meeting point, or the boundary, between the apparatus and the rest of the world that the world and the apparatus are made, in a process of mutual becoming. From this, it follows that the world as we know it depends on specific discursive—i.e., notions, concepts, or ways of seeing, both formal and scientific or informal—and material—i.e., physical instruments, the objects in the world, or our own bodies—arrangements. One could think of, for example, the act of measuring our own pulse using our index finger on the wrist or on our neck. In this gesture, our own bodies get split into two: one is a measuring apparatus, and the other is the isolated thing that we wish to measure: the throbbing of the arteries as blood is propelled through them. Data, in this case a heart rate, can be seen as an inscription of that process of mutual orientation and co-constitution. Agential realism considers phenomena the basic ontological unit rather than things, where the the boundaries between the instruments and the world are fluid. With this sensibility, the very act of making a distinction between the world and the apparatus, the subject and the object, the inside and outside of the phenomena we are interested in measuring, is an active choice that Barad calls an "agential cut" [7]. Within phenomena, agential cuts make locally separable causes (measured objects) and effects (measuring subjects). For example, in measuring our own pulse, we enact an agential cut between the parts of our body that are measuring and the others that are being measured, which stabilizes the world in a way that allows for pulse to emerge.

Agential realism shifts the focus from the things and objects of design, to how design materials, people and the environment intra-act with each other. For design research, intra-action emphasizes interconnectedness with close attention to materiality. It requires a shift in focus from attributes of an individual subject or object toward performances or phenomena as ongoing and emergent. According to Barad [7], in contrast to "interaction", which presumes the prior existence of independent entities, "intra-action" represents a conceptual shift: it is though the particular agential intra-actions of different entities that the boundaries and properties of those determine particular concepts and become meaningful, without having a pre-existing and determinate meaning. Agential realism has been proposed in HCI as a way to theorize and find new ways to design in a world where technologies are increasingly integrated with our bodies, and seen to have a level of agency and autonomy, from artificial intelligence, cyber-physical systems, extended reality, neuro-implants, and others who trouble old notions of agency and easily demarcated human-machine boundaries [39]. An agential realist stance has also been adopted in soma design to both describe the process of mutually orienting the designers' somas, or bodyminds, and the materials they design with, towards the emergence of new aesthetic experiences [106], as well as to reflect on how soma design can be considered a transformative practice, as soma design artifacts become entangled in the everyday lives of end-users [105]. Agential realism has also been proposed as a way to design with data. For example, Lupton and Watson [77] deploy creative collaborative design methods inspired by agential realism that intend to elicit affective and multisensory contexts of people's feelings, practices and imaginaries concerning their digital data. Focusing specifically on biosensing, Howell and colleagues ask what would happen if designers "stopped treating data as an inherently abstract, insight-laden 'thing' and instead turned their focus to phenomena of continually transforming materials and meaning?" [61] and point to agential realism as one way to attend to the materiality of data during the design process.

Central to agential realism, and also to this paper, is the notion of *diffraction* [7]. A representationalist stance is concerned with reflection, which treats data as mirroring a pre-existing reality, focusing on finding similarities and extrapolating from them [56]. Instead, diffraction is a metaphor for inquiry focused on attending to difference, interferences that can be understood as the specific material entanglements which we are part of, our intersecting identities, and the multiple and often conflicting discursive and material practices that constitute our everyday lives. Diffraction is focused on documenting how these different elements may interfere with each other in the ongoing process of producing data. For example, Østerlund and colleagues [85] apply a diffractive analysis to trace, or log, data in an online learning platform to trouble the notions of what learning is, and what roles do volunteers play when engaging the system. Here, we show examples of diffractive engagements with biodata and what can they bring to the design process.

A central point of agential realism is ethics. As Barad puts it, there is a "need for an ethics of responsibility and accountability not only for what we know, how we know, and what we do but, in part, for what exists" [6, p.243]. In other words, performing an agential cut is an act of responsibility, one that makes some worlds possible and others impossible. Hollin and colleagues [57] make an argument for the usage of agential realism as a way to make visible problems with currently established ways of knowing, and show how alternative discursive-material configurations, different ways of seeing, describing and assembling the world could have produced new and more ethical forms of data. When designers perform an agential cut around biodata, we are bringing to life a particular conception of what the bodily phenomenon we want to measure is, and therefore we have a responsibility to be aware of what we are making visible, and what things are we choosing to make invisible, an "ethics of exclusion" [57]. In the case studies below, we show examples of how data was engaged with diffractively, in a non-representational way, and how this contributed to an ongoing articulation of ethical issues and novel ways of designing data.

2.3 Lived Informatics, Lived Data

Our paper builds on and extends the notion of *lived data* by offering expanded consideration of different ways and purposes of living with data. Kaziunas et al. propose *lived data* [69] in describing DIY hacking and tracking efforts of people with diabetes. They recount ways in collecting, analyzing, and living with data around diabetes form highly significant aspects of people's lives and interpersonal relationships. Regarding Rooksby et al.'s attention to physicality, emotionality, and sociality of lived informatics [91], Kaziunas et al. elaborate on the literal physical pain of blood sampling, the emotional life-or-death stakes of diabetes, and the extended dependencies of care work [69]. They describe how, "To date, people have tinkered with just about every commercially available diabetes medical technology except for the actual sensor that measures interstitial fluid (used to determine blood glucose values)" [69, p. 75]. Lived data is related to the concept of *lived informatics* that extends *personal informatics*. The latter refers to tracking aspects of daily life such as activities, health, fitness, sleep, menstruation, among others, while lived informatics emphasizes the practices and social arrangements of tracking in daily life. As put forth by Rooksby et al. [91], lived informatics foregrounds the physicality of tracking, the emotionality surrounding tracking, and ways in which tracking is often a social, rather than individual, practice. Epstein et al. have extended the idea of lived informatics to consider cycles of deciding to track, tracking and reflecting on data, as well as lapses in tracking [33]. Elsden et al. also move beyond personal informatics to explore a broader range of experiences with data [31]. Broadly, the shift to lived informatics and lived data considers a greater variety of engagements with data beyond individual behavior change goals.

One key distinction of our case studies compared to those outlined is that ours describe engagements with data less urgent than coping with a potentially life-threatening chronic illness such as diabetes. So the projects of lived data that we present take a more exploratory approach to various phenomena of interest. Another key distinction is that the projects of our case studies often do explicitly tinker with, modify, or build custom sensors, which measure these phenomena in different ways. As such, these projects can offer unique insights into act of measurement, or the creation of lived data itself.

3 METHOD

We analyze case studies of design research projects to investigate how these projects engaged data in various ways. The design research projects engage different kinds of biodata, data about people's bodies and behaviors. We focus on projects engaging biodata because biodata 'refers back' to the bodies, behaviors, and lived experiences in which it was produced, and thus offers a unique vantage point for considering data's entanglement in ongoing phenomena with Barad's concepts of diffraction and agential realism. The case studies are by no means representative of the space of design research with biodata. They were selected because they illustrate a range of approaches to engaging data diffractively through living with data. As noted by Feinberg [36], there are many examples of data-driven design research, but few focus on documenting the design decisions around data and the reasoning behind them. Therefore, another criterion for selection is that we had access to documentation of the design processes.

To analyze these case studies, we reviewed emails, research diaries, notes, video and voice recordings, and other documentation[1]. With the designers of each case study, we discussed their experiences working on the project and in particular how they approached the biodata involved in the project. What did they initially seek to measure with biodata? What measurement apparatuses (e.g., sensors, logs) did they use, and what kind of biodata was produced? What interesting differences emerged in the biodata collected, whether across people, places, or time? What did they learn from engaging those measurement apparatuses? What did those measurement apparatuses reveal, and what did they hide? How did the use of those measurement apparatuses reshape understanding of the phenomena of interest? We did not explicitly ask about 'living with the data'; this emerged as a common thread. In some cases, design processes explored these questions iteratively, developing and refining measurement apparatuses (e.g., 4.1). In other cases, design processes employed multiple measurement apparatuses in parallel (e.g., a mobile device sensor and hand-written logs in 4.5) to diffractively surface differences.

The case studies illustrate different approaches to diffractively engaging data. Sometimes diffraction was consciously at work for designers who explicitly mentioned Barad, diffraction, and agential realism. On the other hand, sometimes we as authors consider how the design process illustrates tendencies of diffraction, even if this concept may not have been foregrounded for the designers. In retrospectively surfacing and illustrating examples of diffraction in the ways designers lived with data, our goal is not to perfectly uncover the past—as all histories are partial—but instead to surface possibilities for diffractively engaging data that can influence design projects going forward. Although diffractive analysis foregrounds ways that biodata are co-produced by people's bodies entangled with the world, the case studies are roughly ordered from 'inside out', moving from phenomena 'internal' to the body (breathing in 4.1, peeing in 4.2), to biodata 'on' the body's skin (skin conductance in 4.3 and 4.4), to data 'about' the body's movements through space (location estimates in 4.5). Drawing from the case study approach of Irani et al. [65], we use the case studies as illustrations of how engaging diffractively with data can happen during design processes, and how these engagements help address design issues, lead to discoveries, or contribute to an understanding of possibilities and limitations of data.

[1]Each case study had the involvement of at least one of the authors, which facilitated access to design materials.

4 CASE STUDIES OF LIVED DATA

4.1 Case Study 1: Exploring Breathing Through Biosensing

In 2018, a team of designers, engineers and an expert in breathing exercises began a long-term collaboration aimed at designing a novel artifact that would capture breathing data called the Breathing Shell [108]. To start their soma design process [59, 64], the team engaged in a series of breathing exercises. These were guided by the expert, a classical singer, and were followed by discussions of participant experiences. Over time, the researchers started augmenting these exercises with biosensors such as an elastic stretch belt, muscle tension sensors, and accelerometers. The biodata captured through these sensors was visualized or sonified, making them perceptible when conducting these breathing exercises. To facilitate these explorations, the designers created a corset that could be adjusted and kept tight against the body, accommodating different body types and sizes. This corset functioned as an open-ended platform for integrating and experiencing the different sensing mechanisms in relation to breathing.

Each designer documented their experiences of using the corset and the biosensors in paper diaries and a shared Google doc as an ongoing conversation about the design process. As reported in [108], there were no sensors then capable of measuring the nuanced thoracic changes caused by the breathing exercises , which involved purposeful and engaged breathing both with the lower and upper segments of the torso. Slowly the designers started refining their understanding of how breathing affects different areas of their torsos, as well as how aspects of breathing can be captured through different sensors. These included capturing the expansion and contraction of the chest measured through a wearable strain sensor in the form of an elastic piezoelectric belt, or the contraction of abdominal muscles through via electromyography. After five months, the designers decided to experiment with shape-change materials in the form of inflatable pillows developed, which would register pressure drops produced in the torso during breathing. Many different shapes and forms were developed, and each shape had an influence on the type of deformation possible, and consequently on the type of breathing data that could be generated.

During this process, designers explored several placements for the pillows (Figure 1), as well as their possibilities for pushing back on the human body. This allowed experimenting with pillows hacked to function as sensors and actuators, sensing breathing through muscle deformation on the torso and "playing back" this breathing pattern to users against their torso. The data was experienced by designers when they used the sensors and heard the sonified data, as well as afterwards when they inspected the data logs. Moving from exploring only off-the-shelf sensors to developing a new sensing mechanism for this context and engaging deeply with experiencing it on their own bodies, the researchers progressively came to an understanding of what these shape-change pillows functioning as sensors make visible, what they are not able to capture, as well as how they influence breathing. These diffractions helped the researchers shift their understanding of the phenomena that is being measured (breathing) and the apparatuses used for measuring this phenomena (sensors). The custom shape-change pillows became a new apparatus able to capture the progressive

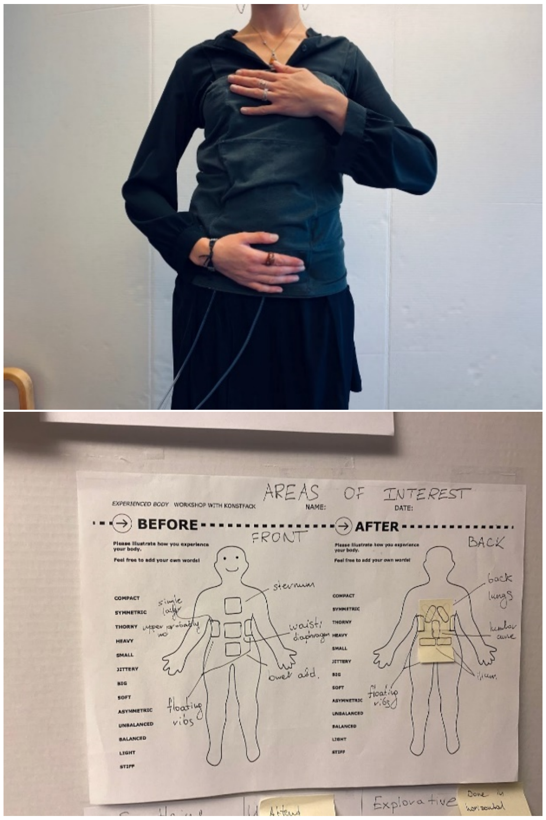

Figure 1: Exploring breathing through pressure sensing/actuating pillows. On the top: a designer explores the corset with the shape-change pillows embedded on it. On the bottom: different placements for the shape-change sensor pillows are noted for sensing breathing through muscle contraction.

re-conceptualization and understanding of breathing and sensing breath.

More than just the sensors, the development of the adjustable corset allowed the design team to become better aware of how the pillows performed and what nuanced aspects of breathing could be captured. The corset became another apparatus measuring the phenomenon of breathing, as it became part of the software that sonified the data coming from each pillow in different frequencies, mapped the pressure data to inflation and deflation of the pillows, and recorded data to be inspected later. New relationships started emerging between inflatable pillows, corset and body. As articulated by the professional signer, *"the experience of a tactile, external representation of my internal body and its movements as I breathe happening through the pillows pressed against by body, becomes a significant component of how I interact with this artefact.... feeling my own body through the corset I can experiment and feel the immediate consequence of utilising different muscles on my torso to move my breath and air around my body"*.

The team invited colleagues to experiment with various placements and shape-change levels, while sitting and working for prolonged periods of time, moving, or lying down. Over time, informally, 25 people experimented with the platform. While doing so, it became clear that different people would benefit from different types of pillow placements, depending on their body type. The corset, in combination with pillows added to it, was able to complement their body, by filling cavities under the vertebrae, for example, and became a type of sensing mechanism (corset and pillows) that was able to capture breathing data from different bodies. To summarize, this design process culminated in the development of an inflatable pillow mechanism able to sense thoracic changes in specific areas in the lower and upper torso, as well as the engagement of the back and front muscles in a controlled way. From this medium-fidelity prototype, several variations of the system were developed for therapeutic settings [67] and for musical instruments [23].

4.1.1 Highlighting Diffraction: A Custom Apparatus to Engage with Instability. This case study illustrates an example of engaging with biosensors diffractively, attending to the differences between bodies, the different ways of defining what breathing is, and consequently of designing with and for breathing. Engaging deeply with breathing as a bodily function through regularly practicing breathing exercises was crucial for questioning and re-defining not only what breathing is, but also how it is manifested and how it affects one's torso and muscle movements.

Engaging with data diffractively throughout the design process led to the recognition of the different agential cuts that could be created between the ongoing phenomenon of breathing and the measurements created by the sensors. This helped in moving away from simply representing breathing, and instead to engage phenomena of how bodies move and breathe, while staying with the differences of bodies. As the phenomena of what breathing is and what it does to the researchers' bodies was shifted, they hacked existing sensors to measure their—gradually changing—understanding of what breathing is, and how it can be sensed. This sensing platform makes it possible to choose what pillow sensors and what placements to use for capturing breathing from diverse bodies, but also for capturing particular aspects of breathing. This research process highlights that capturing breathing data is not stable and thus should not be taken for granted. This also highlights that one could engage in a process aiming to trouble what type of breathing data can be captured as well as how breathing affects the body, revealing the richness of breathing as a bodily function, and the diversity of experiences surrounding breathing among different bodies.

Finally, this process also led to experimenting different ways that breathing can be tied to actuation. Rather than being just a sensor measuring breathing, the pillows also provided a tactile feeling as they inflated and deflated in tandem with the breathing. This caused some wearers to experience a blurring of the boundaries between themselves and the corset [68], representing another agential cut between "body" and "measuring apparatus" that paves the way towards designing for the experience of wearing biosensors through symbiotic, or cyborg relationships [111].

4.2 Case Study 2: Tracking Intimate Somatic Data Through the Pee-ometer

In 2018, a researcher engaged in an autobiographical process of data-gathering and self-labeling of urinary habits over a period of 6 months [54]. This was part of a longer research-through-design study aiming to model the urge to pee, and to understand whether that urge could be predicted, responding to questions such as "what opportunities exist for leveraging personal data to empower vulnerable user groups and caretakers with when, where, and how they might manage private toilet practices?" According to the author and researcher working on this project "following foundational research, design workshops and cultural probes that investigate the training of non-technological objects, people and animals, a pee-ometer with a tangible user interface will be designed and prototyped to predict pee habits, suggest user actions and respond to user training." [55, p395] This excerpt describes the initial intent of the design researcher to predict the urge to pee based on bodily movement. Through a simple technical set-up made for storing her urinary habits, the data took the form of note taking through a custom chatbot in the Telegram chat application that allowed data to be collected by messaging it, and those messages later being exported into tables (Table 1). Initially, the note taking captured two phenomena: liquid intake and the number of times visiting the toilet. She also started approximating the urge to pee through making notes of how much she needed to go to pee. The notes were an open-ended field that could also contain multi-media content such as images. Notetaking would occur in situ, while engaging with the data would occur at different times: at the moment when data was being collected (by sending notes to the chatbot), and after the fact by examining the tables.

Of particular importance was how the act of collecting data changed this researcher's awareness. As the time passed, the researcher started to become aware of how much time and coordination is spent on urination within daily life and everyday encounters with others. For example, she became aware of how she would often go to the toilet before feeling like urinating due to uncertainty about her proximity to appropriate facilities in the near future, or how she would use going to the toilet as an excuse to take a break from work, go for a walk, or as an excuse to interrupt social encounters, as she has articulated: "*when I began trying to quantify my urinary urge through a percentage, the unclear relationship between urge and flow was foregrounded. In particular, it seemed as if an urge to urinate increased not only with a full bladder, but also when access to a previously unavailable facility was restored*" [54, p1216]. Additionally, her orientation and attention towards quantifying this aspect of her life gave rise to new types of interactions with other people. For example, when in the home of a friend after going to the toilet, the researcher recounts having a conversation about the colour of the urine and how this conversation would be too embarrassing to have without quantification as context.

The attention spent on modelling the urge to pee, combined with the engagement occurring when collecting data, transformed the designer's initially naïve understanding of the phenomenon: it shifted her initial understanding of both her own bodily experiences surrounding urination, but also her initial understanding of how to gather data about this bodily function and what data would make sense to capture for modeling and understanding urination. What seemed like something that would depend mostly on liquid intake and output, led to an understanding of peeing as a social act, with the urge as being dependent on social interactions, context, and the complexity of the work needed to quantify and make decisions based on this construct.

4.2.1 Highlighting Diffraction: Meaning-making with Previously Obscured Relations. The data log that began as a record of data expected to be important for modelling the urge to pee initially centred on time and liquid intake only. As the designer lived with the data in everyday life, it became more and more complicated, steering away from simple notions of both peeing, as well as the need to pee. The initial apparatus reducing the urge to pee to a simple liquid intake/outtake made invisible all the social negotiations, access to peeing facilities, the embarrassment of discussing urinary habits, and how all of these contribute to the somatic urge to pee. Thus, the phenomena being studied (urinary habits and peeing data) and the measurement apparatus (data logs and how to read those) gradually shifted. Initially, the urge to pee was approached as being separate from the context, but gradually it was studied as being enmeshed in a social and everyday life context (work, visit to friends, different bodily and psychological experiences, etc).

As the data and designer started to engage diffractively with each other, the designer made a new agential cut between the "self" and the "urge to pee": initially the designer tried to engage with her own bodily data through a diffractive approach towards the urge to pee, the amount of liquid, time, etc, but then she realized that the phenomena being in focus was more entangled with social context. Consequently, she had to rethink the agential cuts as the project went along, gaining a completely new understanding of the phenomenon: it became separated from being only about the body, making social contexts more present. Thus, another agential cut that happened was between "bodily experiences" and "context", resulting in adding new notes around the social and material context pertaining to the bodily function of peeing. The notes themselves became a locus of meaning-making, and further data for the design process. Particularly, by living with this data-as-material, the designer became attuned to the difficulty of labelling an urge, and how quantification of that urge can be used as a lens to surface previously obscured relationships between technologies and people in everyday life. These considerations shaped speculations about designs in future scenarios, and the data log, as a material, was progressively refined into speculative enactments [30] aiming at showing the complexities of data-driven predictive technologies applied to this design space [54].

The data logs of time and liquid intake did not merely reflect reality: rather, a diffractive process surrounding the choices taken behind monitoring her urinary habits took place that created those agential cuts. These enabled her to "take a step back," allowing previously obscured relationships to be highlighted. To summarize, through a diffractive engagement with the monitoring of her peeing data and urinary habits and through engaging with the data more deeply through autobiographical methods, data produced by her body was put in dialogue with other bodily experiences unfolding in her everyday life. The act of measurement and recording created

Table 1: A snippet of Pee-ometer's data log

Timestamp	Day	Type	Note
7/11/2018 16:40:11	Thu	Went	at home, 60% need
7/11/2018 17:17:42	Thu	Went	at home, 10% before leaving
7/11/2018 19:14:40	Thu	Drinking	a bottle of water after gym
7/11/2018 20:19:08	Thu	Went	20 min ago when returned home, had to 30%, return hanit
7/11/2018 20:58:29	Thu	Drank	glass of wine
7/11/2018 20:58:35	Thu	Drinking	glass of water
7/11/2018 22:02:31	Thu	Went	before reading in bed, 10%
7/11/2018 22:02:43	Thu	Message	Drinking a glass of water

agential cuts that made it seem more separate from focusing solely on her own body.

4.3 Case Study 3: Ripple

Ripple is a shirt with small thermochromic patterns that change color based on emotionally responsive biosensors on the wearer [63]. The design of the artifact explores agential realism to push back on the idea that biodata mirrors reality, instead embracing the difference between the symbolic representation of biodata and lived experience. The Ripple system is built so a wearer's skin is in contact with a pair of electrodes and responsive circuitry (Figure 2). The skin's sweat glands respond to the psychophysiological sympathetic autonomic activity and change the electrical properties of the skin. Not only do the electrodes respond to the skin, the skin responds to the electrodes by perceiving their contact. Electrodes on skin can also more deeply affect one's sense of self, for better or worse. For one participant with Ripple, wearing electrodes placed her in an uncomfortably close relationship with a machine. She described how she disliked wearing the electrodes because "they felt like you're connected to something... it does give you that sensation of cyborg-y... I really wouldn't [want that sensation], not at all." For her, the closeness of the machine to the body was particularly undesirable. This participant seems to be trying to draw firmer boundaries between herself and the sensor, perhaps suggesting that in her view Ripple had begun to blur these boundaries.

The circuitry in Ripple sends an analog electrical signal to the microcontroller (Figure 2), which transforms it into a digital numerical value. In this discrete symbolic representation, the skin conductance is now amenable to a wide range of computational analyses, including counting, recording, and statistical or machine learning algorithms. Like many contemporary wearable systems, an algorithm decides what changes in the digital numerical value count as meaningful. The particular algorithm Ripple uses is a crude low pass filter. The filter discards rapid fluctuations in the signal, considering them to be "noise" or not meaningful. The filter selects for slower shifts over the course of a second or more, which tend to be associated with emotional responses in skin conductance such as surprise, fright, stress, or excitement. After filtering, the skin conductance is further transformed into a binary of whether the signal has recently undergone a sudden increase, peaking or not-peaking. These kinds of decisions about what is meaningful versus what is noise are considered uncontroversial standard practice in working with sensors, with a low pass filter being a common choice for skin conductance, yet these decisions foreground how skin conductance as a measurement is socially constructed. If the skin conductance is determined to be peaking, the software triggers a transistor to send electrical power from the battery to the conductive thermochromic threads (Figure 2). Now, skin conductance data has transformed into electrical power, encounters electrical resistance in the threads, generates heat, and changes the color of the fabric display. After this series of material transformations, the skin conductance data is displayed in the form of color-changing threads.

In use, people observed visual changes in the data display and interpreted them, individually or socially. On an individual level, mind, body, and emotions have influenced Ripple's system, and now those influences, mediated by the system, feed back to the person through their eyes. The separation between person / system, user / device, or subject / object is perhaps blurred by the display's enmeshment in clothing. We often feel separate from clothing, but in daily life clothing becomes entangled in self-presentation, style, associations with subcultures, and identity construction [46, 51].

4.3.1 Highlighting Diffraction: Entangled Measurements as Ongoing Cuts. At a high level, viewing Ripple through the lens of agential realism, skin conductance is co-created by phenomena of intra-acting skin, electrodes, responsive circuitry, electrical signals, digital signals, a software algorithm, power delivery to the fabric display, the heat and color change of the fabric display, and the individual and social observation and interpretation of the display. Each material transformation of the skin conductance data happens along an agential cut. For example, the measurement apparatus of Ripple draws an agential cut between the skin's sweat and the analog electrical fluctuations generated by the electrodes in response. Another agential cut can be considered between the analog signal of skin conductance data and the digital signal, a transformation across this divide is made by the ADC (analog-to-digital converter). Another agential cut can be considered between the digital values of skin conductance data on the microcontroller and the electrical power sent to the thermochromic threads, and then the threads that heat up and change color in response. Another agential cut can be considered between e-textile display of skin conductance data, and the way people perceive this data display, and form interpretations of this data. Where, then, is skin conductance data? These components are locally separable via agential cuts, but they are inextricably interconnected as phenomena. Diffractively engaging data here offers alternative approaches to prevalent conceptualizations that treat data as pre-existing, available to be 'collected', to try to accurately

Figure 2: Ripple shirts have embedded skin conductance sensors. They display spikes in skin conductance, a loose proxy for various kinds of excitement, with three embroidered thermochromic pinstripes that gradually change, one by one, between dark gray and white.

mirror, reflect, or represent bodies and the world. Ripple deconstructs any canonical notion of skin conductance data and forces careful attention to the intra-actions of measurement and transformation, a representation that responds to rather than attempts to representationally mirror [10]) reality or lived experience.

Reading the design of Ripple through the lens of agential realism calls attention to skin conductance as an emergent phenomena of intra-acting material, social, and cultural factors that are fundamentally inextricable. This diffractive engagement with skin conductance biodata helps generatively explore design alternatives moving away from the "commodity fiction" [45] of data mentioned earlier. It helps treat skin conductance and surrounding emotional interpretations not as discoveries of an internal state that can be extracted and displayed unchanged. Rather, every measurement or transformation along an agential cut changes the affordances and potential meanings of skin conductance and emotion. It treats skin conductance and emotion not as things, but as phenomena: framing them as such can help designs move away from affect-as-information toward affect-as-interaction [11, 12]. It emphasizes the entanglement of our selves, our bodies, with biosensors, clothing, the environment, and others. In comparison to other consumer biosensing devices that emphasize individual choices for optimized health and productivity, a diffractive approach to skin conductance helps Ripple explore critical alternatives that emphasize interconnectedness and the ongoing performance of being.

4.4 Case Study 4: Discovering Everyday Practices with End-users

Designing Affective Health was an autobiographical design process [24] meant to design for reflection on daily life patterns through biodata in order to help users identify periods of stress and reflect on its causes [95, 96]. Since the project's inception in 2008, designers began living with heart rate and skin conductance sensors, and attempted to map this data to different representations by experimenting with different signal processing algorithms.

One of the engineers working on the project was able to look at the data from skin conductance and notice cigarette breaks, as inhaling tobacco smoke would cause peaks in the autonomic nervous system. Some of the first discussions were whether these arousal peaks caused by the smoke were "good" or "bad." They caused the engineer to first question whether he should quit smoking, while considering the importance of having breaks from work, perhaps filled by other activities. Each designer and engineer using the system would focus on different aspects of their lives as they looked at the data, from habits such as smoking, eating, being with others, or sleeping, all framed under the narrative of stress and well-being. As they were so specific to each person, rather than attempting at representing specific activities, or even stress levels, the designers focused instead on helping users interpret the meaning of skin conductance in the context of stressful situations. It was decided that conductance would be mapped to a colour scale ranging from blue (low) to high (red), but rather than being linear and straightforward it privileged fluent and lively animations that would rapidly change, facilitating playful experimentation and real-time interpretation of data. This mapping itself was the result of an agential cut between the researchers' experiences of their own bodies and the readings of the skin conductance measurements. Specifically, the animations were inspired by how the team experienced changes in their own bodies. For example, getting frightened is a quick reaction and therefore the color transition from blue towards red should be shorter/quicker, while relaxing or falling asleep is experienced as a slower change and should then allow for a longer/slower color transition. Rather than being a representation of a reality out there, the skin conductance data was already designed for a specific purpose, i.e. to allow room for self-interpretation.

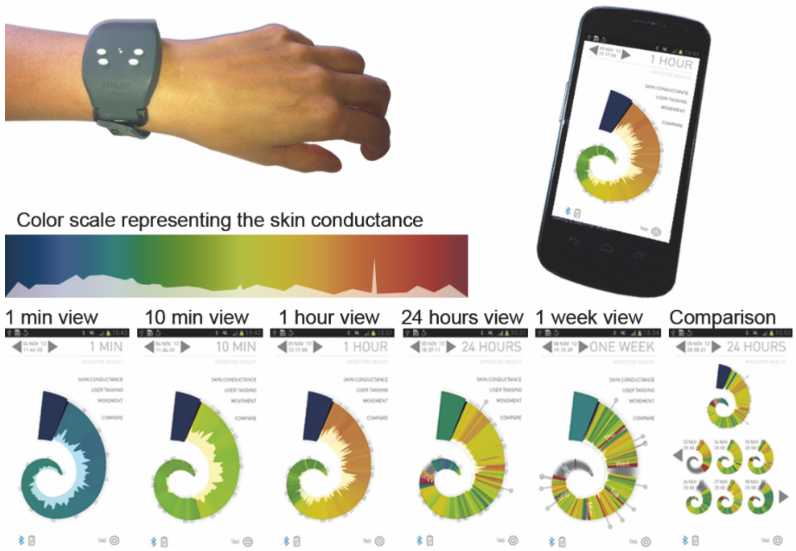

Figure 3: Affective Health representing skin conductance measured from a bracelet.

To achieve this, the Affective Health system acquired the skin conductance signal from the Philips DTI-2 wristband, which streams real-time data via Bluetooth to a phone. The initial processing of the signal was filtered through a second-order low-pass Butterworth filter to remove high-frequency artifacts, digitized, and amplified. Once the data was on the phone, a specially designed algorithm was made to animate the data so that spikes would be immediately visible, and dips would take a bit longer. In practice, this was achieved through passing the signal through a low-frequency filter that was made to make only the longer-term trends of the signal visible—only trends that would occur in windows of 5 seconds. This filtered signal is then transposed twice to form two bounds of a window: one is the maximum value of conductance and the other is the minimum value over a period of approximately 1 minute. The edges of the window became the edges of the color mapping: the lower bound was mapped to the blue and higher bound was mapped to the red in our color scale. This algorithm achieved smooth transitions and responsive color changes. The app then displayed these color animations in the middle of a spiral, and as time passed, the colors would slowly spiral out showing historical data over hours, or days, depending on the time scale selected (Figure 3).

When the system was tested with users outside the design team, it became clear that it was possible to read the data in different ways [96]. A study was conducted where the system was tested in the wild over the period of a month, by 23 participants. The animation peaking rapidly and descending slowly, one of many possible agential cuts of skin conductance, was then lived by the participants, as they were asked to use the system and reflect on the data. Each week they were interviewed and asked to describe their experiences. What became clear is that participants were able to not only contextualize the data within their own lives, they were in fact making their own agential cuts through the data shown, privileging certain practices over others. For example, some participants only used the system to track stress at work. When given to athletes, the skin conductance data was interpreted in terms of ability to reach high performance, as well periods of recovery; some athletes started interpreting the color changes as if they represented temperature and metabolic activity in their bodies: *"Well, yes, Peter was a little bit warmer than me all the time. What we put in there, as a reflection is that I am a person who tends to get cold easily. I run just as much, in terms of time I workout very similar to Peter, but I eat less and get cold much more often than Peter does. Peter eats more, is almost always warm...so that is a difference. It is almost like he has a higher metabolism than me, the basic metabolism kind of."* Other participants started tracking when they met other people and the positive emotions it caused them, e.g. tracking when meeting their children or when going for a date with a romantic interest.

4.4.1 Highlighting Diffraction: Co-designing to Rehearse Re-designing. This orientation towards discovering the practices that skin conductance can and cannot measure in everyone's own different everyday lives is an example of diffractive design with biodata, one that is oriented towards differences, towards understanding the possible agential cuts related to tracking and living with Affective Health. This case study also illustrates how first-, second- and third-person methods can be combined throughout the design process to come to a diffractive understanding of the different practices afforded by the skin conductance data being collected. First, the designers themselves chose to represent biodata ambiguously [103] in a way that allowed for individuals to create their own interpretations. Additionally, third-person methods were deployed to look at how end-users appropriate and live with a system in their everyday lives, observing how data becomes re-designed [36] when it is lived. By analysing how users interpret their own data, design researchers learned about the design context as well as how skin conductance can be further designed to be useful for different practices and activities. By becoming aware of the different possible phenomena that the data could be referring to, the end-users enacted themselves the different agential cuts that could be done around the skin conductance data, in relation to the data representations and their own bodily experiences. In this case, skin conductance data became a material for design not only when it is used by designers, but also when it is put in the hands of users to be co-designed, and co-shaped with them. This case study illustrates how everyday practices can give a particular framing for data, both by specifying particular ways of collecting, ways of presenting and comparing, and also times and places for engaging with it. By adopting skin conductance in their everyday lives, the participants rehearsed possible ways of living with data, pointing at future design directions.

4.5 Case Study 5: Making Sense of Location Through Mobile Network Logs

As our final case study, we take a retrospective look further afield to a 2008-2012 project in collaboration with a multinational networking and telecommunications company. A group of researchers, engineers, and designers, which included the lead author, was tasked with inferring location from cell phone metadata and exploring possible applications of these inferences. This project was before GPS was commonly available, and location-based services for mobile devices presented an exciting yet under-explored space of possibilities. By focusing on location, this case study deliberately stretches the idea of 'biodata,' gesturing towards more varied domains for what it means to live with data. Human location is a direct result of people's behaviors throughout the day, and indicates personal, contextual needs taking place in ongoing social worlds [27, 50]. By focusing on engineers tasked with making more functional inferences from data, this case study may seem to stretch the limits of diffractive analysis as well. Yet, in trying to 'smooth' data and measurement into reliable inference, the team realized social and material properties of the cell tower network, cellphone protocols, and the varied textures of different team members' daily lives. This can be taken as an example of how a perspective on data that begins in lived data and diffractive analysis could be expanded to broader contexts and sites. We do not claim that diffraction was consciously at work for the researchers on this project; rather, we use this case study to suggest latent potential for diffractive analysis to support efforts to draw functional inferences from data—and perhaps move beyond biodata.

The team started exploring how to make use of network cell logs, or "metadata", consisting of time and date of calls, messages, internet connections, and the identifier of the cell tower to which the phone was connected at the time. They developed applications that ran continuously on their own mobile phones to track which cell tower their mobile phone was connected to, over time generating long sequences of cell tower identifiers with timestamps. Over the same period, they carried notebooks and manually logged places personally relevant to them, such as their homes, workplaces, train stations, and shopping malls, etc., to achieve a "ground truth" of location. The notes consisted of a timestamp and an event that represented a place or a route, e.g "2009-02-12 12:34 Catching the 178 Bus from [anonymous location A]", "2009-02-12 12:50 Getting off the 178 bus at [anonymous location B]". These notes were meant to help classify temporal sequences of cell tower IDs into different categories of activity such as transportation type (bus, walking, etc.), "in movement" or "stopped", at "work" or "home", and so on. The cell tower IDs were also geolocalized, either by carrying a separate GPS unit, or through a third-party service able to associate cell tower IDs with a coarse location or region (4). Over time, a database of geospatial data was produced centred around locations where the researchers went about their daily lives.

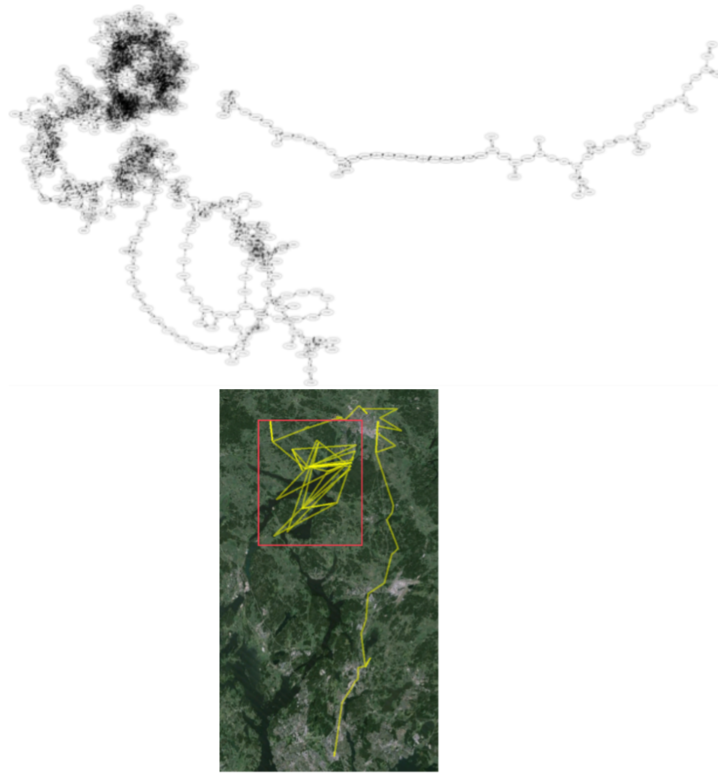

Figure 4: A graph of the network without geographical location, and an image of the network nodes drawn with GPS data. The red square represents one house as seen in the network.

The team met weekly to design visualizations based on different clustering algorithms and unsupervised learning methods. These sessions aimed at understanding the data and showing how the cell tower ID sequences could be used to create location-based services. In one of the meetings, two researchers started comparing their data and noted important differences. One of the project members "E," lived in the center of the city. It was a mystery to him why his phone was out of battery in the morning even though he had charged it during the night. The kitchen table was his place of choice to leave the phone during the night. Although the kitchen table never moved, leaving the phone there caused the signal to alternate between cell towers. In the cellular network, the table was a transition area between two different cells. He noticed that because of the number of log entries caused by his phone. In that room, the phone was in a constant state of indecision over what cell tower's connection was best[2]. A consequence of this constant switching, which demands energy, was that E's phone was out of

[2] This was a problem in early Symbian phones. Given that the phone spends the night in stand-by (i.e. not on a call) those changes remain unnoticed in the cellular network.

battery in the morning. In the same meeting, another researcher, "M," noticed that, for him, many entries were generated only as he travelled by car through a highway at high speed, covering large spaces. M lived in a remote area, a few kilometres from the city. His home, situated by a lake, seemed to be served by one cell tower that covered a large area. The research team soon noticed that his phone was not generating data if he went for a walk by the lake, nor could they distinguish if he was in a neighbour's house or his own. This contrasted with the data he was producing while he was at their workplace in the city. Just by walking around their company's building, they could see the phone generating multiple entries and it was possible—merely by looking at which cell towers were selected—to distinguish between two entrances of the same building, only 20 meters apart. It was immediately apparent to all researchers that factors such as being in a rural vs. urban area will inevitably influence how one can make use of network data for location-based services.

4.5.1 Highlighting Diffraction: Multiple Apparatuses in Performing Difference. The researchers built two apparatuses for producing data. One relied on paper, aimed at producing a "ground truth" of the researchers' self-reported location and movement. The second apparatus relied on specially developed applications to collect cell tower IDs with timestamps. Looking diffractively at the data from the two apparatuses and from multiple team members, surfaced important insights that fundamentally shifted the team's understanding of what the data meant in context. This led to an agential cut between the measuring apparatus and what geolocation data captures in relation to the researchers everyday lives and mobilities. In particular, this process made visible how their mobility patterns intersected with the topographical distribution of the mobile networks, and particularly how the network data could contain huge variability in granularity from the network infrastructure. This also had consequences for privacy: in E's home, it was possible to discern precise location purely through the cellular network; in M's case, only the general area could be discerned—an area that included his home, a neighbor's home, and a nearby lake.

By comparing the notes taken for ground truth, researchers also became aware that, for example, a commercial centre was seen as a cut-through by some who simply passed through it on their way to work, and by others as a place where one could stay for a long time, by for example working from a café. These notes were then compared with network logs, letting the researchers examine the differences and discrepancies between the two streams of data, and between people. This highlights how "ground truthing", an activity often performed by data science workers while detached from the context [80], can also be lived and can benefit from diffractive engagements aimed at showing difference. By resisting for a while the impetus to reduce the world to a model via automated data collection, the researchers could better attend to and connect the cell tower ID data to their own—as well as their colleagues'—lived experience of navigating and occupying places. Living with the data helped diffractively engage the ongoing phenomena of which the data was only a slice, not a reflection of the world. Diffractive engagements with data about people's movement and location led to another agential cut between lived experience of navigating and occupying places in relation to the data captured from these experiences through the existing infrastructure of cell towers in the city.

5 DISCUSSION: DIFFRACTION THROUGH "LIVED DATA"

As diffraction emerges in all case studies, what these projects have in common is that data is "lived with," meaning engaged deeply with, explored, questioned, experienced and scrutinized through different methods, tools and technologies, instead of being taken as pre-existing and available to be collected. For example, in the case of the Breathing Shell (case study 4.1), living with data emerged through first-person experiences and engaging in somaesthetic design methods, making it possible to re-define what breathing data is and how it can be captured from a wide range of people's torsos. With the Pee-ometer (4.2), urinary habit data, initially thought to be local and purely bodily, became elaborated in relation to social and emotional context via autobiographical design methods. With Ripple (4.3), thinking in terms of making agential cuts in an ongoing phenomena shaped the design of sensing, analyzing, and displaying skin conductance data. The Affective Health case study (4.4) also engaged skin conductance in a different way, by diffractively analyzing the many varied experiences and interpretations participants had around skin conductance, expanding notions of what this data can mean. In the case of the cell phone location data (4.5), a weekly process of diffractive comparison of data among different people helped surface new relationships and meanings. Taken together, the detailed recountings of the case studies offer specific illustrative examples of how design researchers can engage data diffractively, and how diffractively engaging data can enrich design processes.

Engaging personally with technologies is central to how artists engage with biosensors [35, 82], how engineers tinker with technology to gain an understanding of its possibilities [81], and even how data science workers engage with data [80]. By familiarizing themselves with the data they learn not only what data is *intended* to represent, but also what it *could* represent. We see living with data as building on these situated practices. Living with data also builds on practices of those who self-track and quantify themselves [38, 91] who, by living with data, are constantly re-inventing it and putting it to different uses—practices we examined with the Pee-ometer case study (4.2). When looking at how people use self-tracking technologies, Rooksby and colleagues found that "people choose, use, interweave and abandon various technologies in their own, lived efforts to improve their health" [91]. Rather gaining straightforward actionable insights from data, self-trackers may have a complicated relationship with data, questioning it, appropriating it while negotiating conflicting goals. Another aspect of this is echoed in Forlano's auto-ethnographical accounts of living with an insulin pump and a glucose monitor [38], where mundane everyday rituals, such as getting dressed, or frequenting different social settings are all reconfigured through the practice of caring for the tracking device, negotiating how socially acceptable it is, or that it has enough batteries to go through the day. In a sense, our concept of lived data extends Rooksby et al.'s concept of lived informatics, but instead of focusing on the *end-users'* lived experiences with data, lived data focuses on the *designers'* lived experiences with data and how they incorporate theirs and the experiences of others (colleagues, end-users, other stakeholders) into their design research processes of imagining and living with data in various forms.

Briefly, we also consider how diffraction, as an approach to engaging with data through living with it, compares to other kinds of data work, such as data science. In data science practice, which often follows a representational epistemological stance, the goal may be to employ data analysis methods towards achieving high accuracy in modelling a particular phenomenon. By adopting diffracting engagements with data, we point instead at methods that offer alternative ways of defining a particular phenomenon, including the urge to pee, breathing, and moving through the city. When data becomes a lived material, thick with context, it becomes less of a way to isolate a particular phenomenon or achieve a solution for an already-determined problem. Instead, this process can advance understanding of what interpretations of that data may enable—thereby defining what the phenomenon might be and how it can be sensed and measured to attend to different factors. For example, in the case study with cell phone mobility data (4.5), diffractive engagement with cell tower ID data provided the research team with a richer understanding of the relationship between cell tower IDs and location. This surfaced factors that were essential to consider when attempting to model location from cell tower ID. In this way, we echo Alfaras and colleagues [1], who recommend making biodata felt in the body to enable exploration of its possibilities. We additionally propose that data need not necessarily be made tangible, as they suggest, but instead be made available through a wider range of artifacts and forms of representation, as we have shown in the case studies above.

To articulate how lived data may offer an approach for diffractive engagement with data, we started by considering data as a product of entangled humans and materials in ongoing phenomena. Our case studies focus mainly on biodata, examples of diverse forms of data being adopted, re-interpreted or questioned through being lived by designers as well as end-users in some of the case studies, but we do not see this approach as limited only to biodata. How can one engage in working with data diffractively? How can one design with lived data and what might that entail in terms of practices of designers? We discuss these questions in regard to the methodological and design implications of this approach but also in regard to the value of this approach for data design research more broadly. Drawing from the case studies, we discuss how to practically engage with data diffractively and some approaches a designer could adopt in achieving this—what we call *diffraction-in-action*.

5.1 Methodological Implications: Towards Diffraction-in-action

We start with the notion of design as a reflective practice that operates in conversation with materials, after Schön's *reflection-in-action* [99], which has been greatly influential in design and HCI. In Schön's classical example, architects create virtual worlds through sketching, where different arrangements of materials and technologies are tested on paper, allowing for the architect to gain a progressive understanding of what they afford and how can they be designed with. Reflection-in-action works well when designing with materials, as the material can speak back to a designer in a productive way. Yet, as Manzini argues, novel materials can require significant changes on how designers work with them [78]. Data as a design material 'points back' to phenomena outside itself; data 'references' [71] the phenomenawhere it was co-produced; data does not reflect or mirror those phenomena. For designing with data, treating data as capable of 'reflecting' the world risks obscuring ways in which data abstracts, simplifies, reduces the world into particular measures. Design research has critiqued claims that data can straightforwardly 'represent' or 'reflect' the world (e.g., [10, 72]). Engaging data diffractively offers a way to understand data differently and reposition it as something that is lived, situated, and contextual, making designs that are closer to the entangled phenomena of being in the world.

In seeking alternative approaches for designing with data, we turn to Barad. Barad's agential realism offers a potential alternative to the old conundrum of whether the outside world can be reflected and mirrored. Instead, agential realism points to the contingency of all human activities, instruments and observations. Approaching data diffractively allows us to test out and experiment with different ways of orienting sensors, people, and environments to each other, and create new agential cuts that may be more thoughtful and more respectful of human differences. Barad critiques reflection as a mode of inquiry aimed at creating models of the world, that is "set up to look for homologies and analogies between separate entities" [6, p.88]. In this paper, we consider what it could mean to move beyond reflection and representation as modes of working with data, and articulate emergent instances of *diffraction-in-action*. As with other researchers [56], our intention is to move within and beyond a reflective practice rather than displacing it or treating the two modes of inquiry as opposite.

Here, we move beyond reflection when we start documenting patterns of difference, and testing how different ways of becoming [5] with the world and with sensors can produce different forms of data in general or biodata in particular. Ultimately, when we are designing with data, we are also designing a world where the sensors and the systems we design can exist in the first place [42], including the practices that produce data [89] and the movements and bodily orientations of people towards sensing mechanisms [34]. This form of world-building can be done by designers, as they investigate, for example, how tracking the urge to pee changes their relationship to others and to the spaces they occupy (case study 4.2), or by users when they adopt skin conductance data in their own everyday practices (case study 4.4). Because of this, when we design with data we are always in the process of what Redström calls design after design, "a series of processes in which the product of one design activity becomes the material for subsequent design activities: a textile is designed and then used as material for a dress" ([90] cited in [37]). We can conceive of design research with data as a socio-epistemic process [87], a world-making activity [17], as a collection of practices that orient different actors, including data scientists and users, towards thinking and communicating about future uses around data.

We argue that when designers engage diffractively with lived data, rather than taking things for granted, or aiming at a clear, controllable, well-defined application, the complexity of everyday life becomes central to the design process. Because of this, the practice of designing with lived data can help address the difficulties of designing for entangled practices, by surfacing specific design directions related to different forms of measuring, quantifying, and producing data. To help designers engage with with data in this way, we offer three orienting principles:

First, our case studies detail how **engaging with data can be an open-ended and undefined process. Resisting the impulse for actionable insights early on, design researchers can surface more nuanced or alternative meanings of data.** Engaging in open-ended data explorations can help show how data depends on the practices that give it meaning. For example, the Pee-ometer (case study 4.2) exploration surfaced a range of social and contextual factors influencing the data that sought to track a private, internal bodily urge. The cell tower project (case study 4.5) teased out ways in which data of one's personal individual location, or at least the ability to effectively describe or measure or communicate this location, deeply depends on the surrounding geography and infrastructure of cell towers, lakes, population density variations, and so on. Designing Affective Health (case study 4.4) surfaced a range of user-generated meanings for skin conductance. Surfacing the practices that gave data meaning prompted realizing, troubling, or reworking agential cuts as processes of measurement were reworked to explore phenomena of interest (as articulated in more detail in 4.2.1, 4.4.1, 4.5.1). Overall, the case studies, by documenting lived engagements with data, and by attending to the differences between bodies, identities, contexts and material conditions, brought forth novel ways of seeing the world and emergent meanings of the data itself. Put another way, this methodological implication can be also read as suggesting to other design researchers to consider how to practically deploy diffraction-in-action when working with data, as a complement to reflection-in-action in design.

Second, and related to the first, the case studies illustrate how **diffractively engaging data in a slow, long-term process and resisting the impulse for efficiency, can help surface, articulate, and explore practices around data**. We argue that the slowness of living with data is a fruitful path to engage with data diffractively in design processes, allowing new relations to data and understanding it both as something that we can design with, as well as something that we can design. Rather than prescribing a specific method for conducting these slow engagements, the case studies in this paper illustrate different configurations and design methods. First-person methods such as autobiographical design or soma design [113] (case studies 4.1 and 4.2), where the designer's body and experience are problematized in relation to data, or combining first-person with second person methods (case studies 4.4 and 4.5) over time highlights differences in how bodies and behaviours are registered differently by sensors and data sources. Third-person methods (case studies 4.4 and 4.3) that inquire into adopting, appropriating, and understanding data into everyday life can play an important role in scaffolding new relationships with and understandings of technologies and digital materials during design processes. What these methods have in common is that they all suggest potential paths towards allowing moments of diffraction to emerge. They can capture and articulate thick descriptions of how data is woven into practices or can be used as a material to create new ones.

Finally, and building from the previous two principles, our case studies suggest ways designers can **hold space for messy, ambiguous data that requires active interpretation, resisting the impulse for clean and tidy data. This shifts the goal from designing to provide expedient insights with data toward designing for a process of balancing open interpretation with scaffolding interpretation.** Drawing from the case studies, we found that the artifacts designed to produce and display data can be productively used as a material in the design process, when they are designed to be both concrete and open for constant adaptation, experimentation and appropriation. Examples include designers creating data logs (case study 4.5), data visualizations that emphasize data's material transformations (case study 4.3), a prototype with sonification and shape-changing couplings of breathing data (case study 4.1), and applications deployed with end-users (case study 4.4). All of these design artifacts can be seen as ultimate particulars [104], as they put forth a particular understanding of the world, while simultaneously being open-ended enough that they can lend themselves to being interpreted (and lived with) within different practices. One strategy to achieve this is to use ambiguity as a resource with the aim of spurring different interpretations and allowing for discussing possibilities and practices that the data lends itself to [43]. Another strategy used in the cell tower case study (4.5) was maintaining multiple manual logs of self-tracked observational data that complemented and added context to the automatically collected data; with the Pee-ometer (4.2) case study this manual log was the primary form of data and evolved and expanded over time. Overall, allowing diffraction-in-action to emerge in varied ways through the case studies revealed surprising meanings from the data and opened new pathways for design.

Taken together, the principles above describe living with data and taking it seriously over time. However, this living must be done in a continuous dialogue with data, so that we know while we are exploring a phenomenon that there is a correspondence between what we do, what we feel, what we are able to articulate, and how technologies are able to sense us. More than first-person engagements with a material, the value is in the encounters between different designers, end-users and their data, and how the emerging mosaic of experiences shapes the expanding understanding of the phenomenon being measured, be it breathing, moving in the world, psychosomatic arousal, or anything else. This expanded understanding is what forms the basis for novel conceptual infrastructures [36], sensing mechanisms, and so on. In short, it creates the premises for imagining—more than imagining, living in—what the world can become with data in it.

6 LIMITATIONS AND FUTURE WORK

Although we describe agential realism and diffractive engagements with data as a tactic for design research, we do not follow Barad's original idea of de-centering the human. Instead, we specifically centred the bodies and experiences of the humans we design for and with. This agential cut made sense to us, as biodata especially pertains to humans, their bodies, and human-centered practices, and therefore our ethic-onto-epistemic commitments are towards the humans we design for. This perspective, however, does not account for how biodata production can affect other living beings, or other non-human agencies. Engaging with lived data could be done attending to the perspectives of non-humans, highlighting for example different environmental impacts.

Additionally, we have not applied an intersectional lens [98] in our analysis. This was due in part because we were not able to pick up on case studies who have applied this lens in their lived engagements with data. The case studies in this paper are predominantly focused on white European non-disabled bodies and practices. However, we follow Spiels' recommendation [102] not to leave the bodies in our paper unmarked, and call for future work that explicitly addresses these dimensions.

6.1 Data Beyond Biodata

Reflecting on our approach beyond solely biodata to account for design research that engages with data of other forms, we see a value in studying in the future how diffraction can be a fruitful approach to adopt when working with for machine learning. This builds on previous work in HCI that has proposed turning machine learning into a design material, surfacing capabilities and limitations of machine learning models [29, 116]. Our work relates to this research, since data is a crucial component of machine learning and, more generally, AI. But rather than approaching "AI" as a unified concept, we follow Churchill's advice for deconstructing it into "a set of techniques and approaches that process data for specific purposes (that behave) in specific contexts with specific bounds" [21]. Data can be produced and processed in many ways that do not include the complex models usually associated with machine learning but are instead more closely related to classical statistics [19]. These transformations can be more predictable and explainable than the typical machine learning models whose inner workings can be difficult to assess [112]. Nonetheless, even more predictable data transformations can be inscrutable and opaque to those without technical training (including most designers and end-users), and therefore the problem of designing with data for all these cases remains. Although designing with AI and machine learning entails engaging with the specific affordances and capabilities of data analytical methods [9, 116], a great number of issues about designing with machine learning are indeed about designing with data [76], such as how to produce "good" training data or understanding how machines are able to "see" the world [4].

7 CONCLUSION

In this paper we examined how data-driven design can be fruitfully approached by living with data. By this we mean to emphasize the prospective aspects of data that is in the process of being designed, as it is experienced and entangled in the everyday lives of designers. In our case studies, we build from biodata-based projects to show how data can be lived through methods that allow designers to, when attending to specific phenomena, become aware of the boundaries being produced between the specific material entanglements of which we are part of, our intersecting identities, and the multiple and often conflicting discursive-material practices in our everyday lives. We suggest that research centred on designing data by living with it can be useful in defining novel problems, articulating and surfacing conflicting needs, and proposing new solutions in a designerly way. Our aim with this work is to develop pathways for others to engage in critical, diffractive design research showing alternative ways of approaching data as a design material that is attentive to how data is embedded in everyday practices, to help produce more humane data-driven societies.

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