Unpacking the sociotechnical challenges of IoT design work in practice

Thesis submitted to the University of Nottingham for the degree of
Doctor of Philosophy, March 2023.

Teresa Castle-Green

Supervised by

Dr Stuart Reeves
Prof Joel Fischer
Prof Boriana Koleva

"millions of people go to work each day to do things that almost no one but themselves understands but which large numbers of people believe they know enough about to set policy, offer advice, or redesign". - Stephen R Barley

Abstract

The term 'Internet of Things' (IoT), was coined in 1999 (Ashton et al., 2009), and has continued to grow under this heading since its conception with a number of subheadings developed (such as, the Industrial Internet of Things (IIoT)) to give further classification as the field has expanded. By 2014 the IoT was being considered as an industry in its own right, with *"the potential to have a greater impact on society than the first digital revolution"* (Walport, 2014, p. 6). The Internet of Things is a growing industry spanning many different markets and sectors with worldwide device forecasts going from 9.7 billion in 2020 to over 29 billion in 2030 (Vailshery, 2022).

As the industry matures it is becoming much easier for businesses and individuals to create IoT products and to release them onto the market. Components and resources are more readily available and a range of supporting services have been developed. Connected devices can now be seen in virtually every business sector. However, there are many design challenges associated with IoT design that have not yet been addressed in the academic literature. For example, the embedded, long-term, infrastructural nature of the IoT presents a somewhat unique design space for practitioners. The many layers of products and services add complexity to the task of design, both for new product design (Lee et al., 2019b) and modification of existing deployed systems. As embeddedness is core to the vision of ubiquitous computing it is important for research to move beyond the lab into real-world deployed settings (Fox et al., 2006). This is of partic-

ular importance to address theory practice gaps where research attempts to influence and inform interaction design. Investigating the existence and extent of a theory-practice gap requires a closer look at how interaction designers within the commercial world actually work, how their roles are organised and what constitutes professional competence (Goodman et al., 2011).

The aim of the research in this thesis is to explore the challenges faced by design practitioners within the IoT industry and *their* methods of addressing them. This is with the intention of attending to the theory practice gap through provision of insights for the purpose of informing the creation of methods, practices and further academic research into the work of designing the IoT. The research was guided by the primary research question: 1) How do IoT related design team organise their work? which is addressed through the secondary questions of: 2) What design challenges are being faced when designing for the IoT within a commercial context? 3) What design practices are being applied to IoT related design work within these settings, and how?

The findings reported here answer these research questions through the following contributions. 1) Identification of relational tensions within the process of IoT related design and demonstrations of practitioners methods of foregrounding them. 2) Demonstrations of the ways in which practitioners maintain visibility over tensions and product service layers to situate design reasoning. In particular, generation and use of notions of elemental states as a form of infrastructuring work, which builds on previous discussions of infrastructural inversion (Bowker, 1994; Simonsen et al., 2020) and the use of decision trees as a form of user journey mapping (Endmann and Keßner, 2016). 3) Identification of additional roles and responsibilities of digital plumbing (Tolmie et al., 2010; Castelli et al., 2021) and data-work within the IoT design space (Fischer et al., 2017).

Acknowledgements

Sincerest thanks to my supervisors for constantly steering me back to the point every time I got distracted by interesting side avenues. They provided me with endless valuable advice, delivered with patience, understanding and unwavering support. Without this amazing team behind me I would not have made it through this challenging journey. Two children joined me along the journey as our family expanded from 2 to 4. Words do not do justice to the gratitude I feel to them and my husband for the support they have given me and for their understanding and patience regarding the hours I have spent at a computer instead of engaging in family time with them. I love you all!

I would also like to thank my wider family and network of close friends for listening to my attempts to explain what my PhD is about, and for engaging in those conversations with me. I realise at times these were very incoherent descriptions! I would especially like to thank my parents for always supporting me in everything I do and of course for the childcare support and proof reading efforts. I'm sure it wasn't the most interesting read. Thanks also to Hannah for the most amazing macaroni cheese delivery right when I needed it.

On a more formal level this research would not have been possible without the support of UKRI the University of Nottingham and the Mixed Reality Lab. Thanks also to all the companies who have allowed me to collect data and the practitioners who have spoken to me either to participate or just to allow me to tell them about the work I am doing. And of course, thanks to the reviewers who have given me valuable constructive feedback on my various paper submissions.

For everyone else who has supported me and believed in me throughout this process (there are too many to list), thank you!

Contents

List of Tables

List of Figures

Publications

Publications supporting this thesis

Teresa Castle-Green, Stuart Reeves, Joel E. Fischer, and Boriana Koleva. Revisiting the Digital Plumber: Modifying the Installation Process of an Established Commercial IoT Alarm System. Computer Supported Cooperative Work (CSCW). 2023. - ECSCW conference contribution.

Teresa Castle-Green, Stuart Reeves, Joel E. Fischer, and Boriana Koleva. Decision trees as sociotechnical objects in chatbot design. In Proceedings of the 2nd Conference on Conversational User Interfaces, CUI '20, New York, NY, USA, 2020. Association for Computing Machinery. - Winner of a CUI 2020 Honourable Mention.

Teresa Castle-Green, Stuart Reeves, Joel E. Fischer, and Boriana Koleva. Designing with data: A case study. In Presented at the CHI'19 Workshop: New Directions for the IoT: Automate, Share, Build, and Care, 2019, May 2019.

Chapter 1

Introduction

The Internet of Things (IoT) is now considered an industry in its own right. It spans many markets and sectors with some form of connected products being found in almost every home and business across the UK. These 'smart' products become embedded into people's lives as part of a sociotechnical information infrastructure. The nature of these products presents a number of opportunities and challenges for designers as a result of their connectedness, allowing for an ongoing service element to be added, using sensor data to increase the value to customers and businesses alike. As complexity is added through the multi-layered infrastructural nature of these products and services, this in turn adds complexity to the structure and collaborative work of professional design teams. This thesis will explore the opportunities and challenges that emerge from the nexus between these layers from an industry perspective to provide insights for academics, practitioners and policy makers who wish to support design practice within this complex arena.

This introductory chapter first provides an overview of the problem space in which this research is situated, before introducing the author's background, followed by an outline of the research aims and approach taken to addressing the problem space. The final sections present an overview of the forthcoming chapters and contribution statement.

1.1 The research problem/area

While there is some debate around the exact emergence of the term, the general consensus seems to be that the 'Internet of Things' (IoT), was initially coined by Kevin Ashton in 1999 (Ashton et al., 2009). The IoT has continued to grow under this heading since 1999 and a number of subheadings have been developed (such as, the Industrial Internet of Things (IIoT)) to give further classification as the field has expanded. From there on the possibilities of the IoT continued to grow with devices being produced crossing many diverse sectors and applications. By 2014 the IoT was being considered as an industry in its own right. A report by the UK Government's Chief Scientific Advisor states a commitment to supporting the growth of this industry and a belief that it *"has the potential to have a greater impact on society than the first digital revolution"* (Walport, 2014, p.6). Over recent years it has become much easier for businesses and individuals to create IoT products and to release them onto the market. Components and resources are more readily available and a range of supporting services have been developed. Connected devices can now be seen in virtually every business sector, with the number of deployed IoT devices estimated to reach levels of 29 billion in 2030 (Vailshery, 2022).

Due to their multifaceted nature, IoT products and services have been identified as presenting somewhat unique challenges for designers as they navigate new risk and value models associated with combining the different technological layers (Lee et al., 2018). Within both academic and industry literature IoT devices are often thought of and described with a focus on the technology layers, for example, as consisting of the four basic components of devices or sensors, connectivity, IoT platform and applications (Karie et al., 2020). However, the ever expanding network of embedded devices into our daily lives and routines contextualises this as a simplistic view which fails to take into account the sociotechnical complexities of these products and services that must be navigated by design teams working with them. For example, due to both the heterogeneous and long-term nature of managed IoT systems, complexities of stakeholder diversity often materialises. These diverse actors may include, hardware engineers, software engineers, technicians, product owners, network specialists, data scientists, user interface (UI) designers, solutions architects and field engineers – this level of diversity is of course not necessarily unique to the field of IoT, however, it is a notable challenge for collaborative design work in this context as there are a number of differing 'object worlds' (Bucciarelli, 1988) to navigate and combine during design reasoning activities. In this way the technocentric views of current research has not delved deep enough into the relational challenges that present in this space to fully understand collaborative IoT design practice methods.

By taking an information infrastructure perspective (Star and Ruhleder, 1996; Neumann and Star, 1996; Star and Bowker, 2006) it is possible to see additional layers within these products and services as various social processes and human interaction layers are incorporated to make up a complete product-service infrastructure. This sociotechnical view incorporates the relevant knowledge-bases, work practices and related resources relied upon to achieve assigned tasks and goals (Pipek and Wulf, 2009), including individuals within related roles such as designers, developers and users, conceptually incorporated as elements within the information infrastructure (Bowker et al., 2009). In this way a sociotechnical view incorporates the intricate and interconnected relationships between social and technical factors within and surrounding an IoT system. Thus acknowledging that interactions between technology and social elements are mutually influential in shaping the overall system. This thesis aims to unpack design work that incorporates the complex relationships between these different sociotechnical layers of IoT products. In particular, drawing on the notion of infrastructuring[1] (Karasti and Syrjänen, 2004) to uncover and conceptualise insights relating to design challenges that are specific to the IoT context.

Many of the design challenges of interest to Human-Computer Interaction (HCI) and Computer Supported Cooperative Work (CSCW) in relation to the IoT or more specifically to ubiquitous computing, are in line with those discussed in the infrastructure discourse. Since Weiser's vision of 'invisible' computing (Weiser, 1991), much of the focus of this area of research has been on the capabilities, opportunities and limitations of the technologies themselves (Gubbi et al., 2013; Patel et al., 2017), regarding the embedding of technologies into the home environment and domestic routines (Crabtree and Rodden, 2004; Soro et al., 2018), use and privacy of data (Fischer et al., 2016; Lodge and Crabtree, 2019) and that of user interactions with domain specific devices (Brereton et al., 2015). The design insights presented within these areas of research all allude to challenges of embeddedness, links to practice, working with installed bases and (in)visibility as core within IoT design settings.

While research in the field of ubiquitous computing and the IoT has presented these challenges of embeddedness and invisibility-in-use as central features within IoT design, with the exception of Lee et al. (2018, 2019a) there has been little focus on *how* IoT design work is materially practiced within industry environments. In particular, methods used by practitioners to address and navigate core sociotechnical design challenges within industry contexts. A further challenge facing commercially based design teams that is often missed within research based prototype studies, is that of modifying existing systems that are already deployed, i.e., moving beyond the view of initially embedding a thing to also consider the evolving nature of systems and routines. This lack of research points to a potential theory practice gap as practitioners navigate these challenges on a daily

[1] The term infrastructuring refers to the processes of design and maintenance which adapt socio-technical elements of information infrastructures over time

basis while academic study in this area lags behind.

Fox et al. (2018) focused on the wider impact of IoT deployments by highlighting the roles and concerns of organisational actors with collective responsibility for maintenance. In particular they demonstrate a need to consider longer-term elements of IoT installations in relation to use, service and reworking of infrastructures. The Odom et al. (2016) suggestion of the 'research product' further supports this growing call to address questions of embeddedness and interaction beyond that of the research prototype and initial installation work. While these papers build nicely on the call to 'move beyond the lab' (Fox et al., 2006), practice based design studies are also required to deepen our understanding of the various complexities involved in providing support for professional digital plumbers[2] working within industry settings. Particularly in relation to the collaborative nature of the infrastructuring and design work that supports it.

As with many scientific disciplines HCI has an acknowledged research-practice gap. This has been discussed by a number of researchers in the field. For example, Norman (2010) argues that a gap exists and that it's due to differing skill sets and motivations between the two groups (academics and professionals). He suggests that translation work is needed to bridge this gap. This involves taking insights from academia and translating them into usable forms in the practical sense and equally translating challenges from practitioners into research insights within academia. He does not however, offer much in the form of direction on how he thinks translation work should be approached. Goodman et al. (2011) also discuss this gap. They suggest that to investigate the existence and extent of a theory-practice gap we need to take a closer look at how interaction designers within the commercial world actually work, how their roles are organised and what constitutes professional competence. For this reason it is important to take a deeper look into the practices of IoT designers and

[2]The term digital plumbing refers to the installation and maintenance work of the physical elements of IoT systems, as defined by Tolmie et al. (2010)

to move beyond the research through design approach (Zimmerman et al., 2007) that is common within ubicomp research.

By taking an ethnographic approach to study the sociotechnical work of industry practitioners, this thesis contributes to the practice-oriented program of CSCW (Schmidt, 2009). The approach is consonant with a broad 'turn to practice' in HCI (Kuutti and Bannon, 2014) and a long history of studying infrastructures in CSCW (Karasti and Blomberg, 2018). Thus this thesis aims to increase our understanding of the work of practitioners within the commercial field of IoT, so as to better define related roles and approaches to design. In turn this can be used to inform the design of tools, methods and frameworks aimed at supporting the work of commercial IoT systems design.

1.2 Author's background and motivation

Design as an industry endeavour (as with anything else) is encased within, and influenced by, its environment. Even with the best intentions of 'Research and Development' or 'Innovation' teams to separate design work from core business objectives there are always numerous stakeholder motivations steering and shaping both the process and the outcomes. At times I have found this to be frustrating, particularly when tensions arise. However, it is a necessary factor in ensuring the work of commercial design gets done. As a previous business owner I understand the importance of commercial viability of resource use and outputs and this often means that design compromises need to be made. Having seen and experienced these challenges first hand as a user experience professional within web and mobile app design settings, I was keen to see how the work unfolds in more complex arenas with a wider circle of core stakeholders and naturally occurring environmental challenges. The IoT field is an industry which is still developing and is finding its own various design identities. I believe this makes it a fascinating arena in which to study the collaborative work of design practice and one which has not yet been properly considered within the academic research to date.

1.3 Research aims and approach

This section describes the main aims and objectives of the research and introduces the three research questions this thesis addresses.

1.3.1 Research aim

The aim of the research is to explore the sociotechnical design challenges faced by design practitioners within the field of the IoT and *their* methods of addressing them. This is with the intention of providing insights for the purpose of informing the creation of frameworks, practices, policy and further academic research into the work of designing the IoT.

1.3.2 Research questions

To address these aims, the research was guided by the following research questions:

- How do IoT related design teams organise their work?
- What design challenges are being faced when designing for the IoT within a commercial context?
- What design practices are being applied to IoT related design work within these settings, and how?

1.3.3 Research approach

The research questions were addressed through three empirical studies of industry based, IoT related design work. The first study, as described in chapter 4, offers an industry overview obtained through exploratory fieldwork at various industry events, followed by interviews with 11 practitioners working within the IoT space. The purpose of this study was twofold. Firstly, it provided an overview of the IoT industry to situate and underpin the subsequent fieldwork studies. Secondly, it provided a thematic report of challenges and opportunities based on practitioners accounts of their work. This industry overview is supported by two detailed ethnographic case studies, which use an ethnomethodological approach (Garfinkel, 1967) to unpack members' methods of making their actions accountable as this or that activity as they collaboratively do IoT design work. These case studies serve to unpack design practices at a deeper level than those uncovered through the interviews and events.

1.4 Overview of forthcoming chapters

Chapter 2 - Related Work This chapter provides a detailed review of multi-disciplinary literature to provide a conceptual grounding for the thesis. This chapter also introduces the IoT as a distinctive design space and demonstrates a gap in the research in relation to understanding *how* the unique design challenges within this space are addressed by practitioners. Core concepts in relation to studies of design practice and infrastructuring are also described here to provide a grounding for this research. This literature serves to present a conceptual basis for the subsequent empirical studies of this thesis and to provide context to the research questions.

Chapter 3 - Methodology Discusses the methodological approach taken to exploring the research gap highlighted in the previous chapters. The chapter explains thematic analysis as the methodical orientation taken to interviews, and ethnomethodology as the approach to ethnographic fieldwork. Reasoning around the selection and use of these approaches along with the practicalities of their application and access challenges associated with undertaking this type of in depth research within commercial settings are also discussed here.

Chapter 4 - Study I - Industry overview

This chapter presents an overview in the form of reports of informal fieldwork at industry events along with a thematic report of a semi-structured interview study with 11 industry practitioners. The findings of this study highlight the variety of different design contexts within the IoT and showcase the related design challenges and approaches through practitioner accounts of their work. The responses from the interviews highlight core themes of embeddedness, long-term usage and business constraints as key areas in which these challenges arise.

Chapter 5 - Study II - Modifying an IoT alarm system

Chapter 5 uncovers challenges relating to the modification of a fully deployed and managed IoT alarm system within the leisure and holiday industry. This case study builds on the findings in chapter 4 by taking a closer look at the design work of modifying a complex sociotechnical infrastructure of this nature and the ways in which members of the setting brought invisible layers and processes to the fore. The study unpacks a product team's trouble shooting session occasioned by digital plumbers experiencing inconsistent, unexplained wait times during device installation. This resulted in design changes being made to the related technology and operational processes. Through this, demonstrations of infrastructural inversion[3] are presented as a method used by the members of the setting to uncover tensions and support design reasoning.

[3]Infrastructural Inversion (Bowker, 1994) is the process of intentionally foregrounding relationships between sociotechnical elements of information infrastructures to gain visibility over the infrastructure itself rather than the activities it supports

Chapter 6 - Study III - Prototyping a data-driven chatbot

This chapter presents a case study of a large energy company's R&D team as they undertake two weeks of sprints to prototype a data-driven energy-advice-giving chatbot. The team draw on smart thermostat data alongside other data streams to generate personalised advice to customers. This study builds on the foundations laid in chapter 4 by delving deeper into the challenges of using IoT data as a material for design (i.e., doing data-work). This also builds on chapter 5 through demonstrations of infrastructuring, as the team work to design the multiple product and service layers. Tensions within the design process and the ways in which the team navigate them using decision trees and notions of elemental state[4] to support their design reasoning are also unpacked here.

Chapter 7 - Discussion

This chapter pulls together the findings from the 3 empirical studies to present design challenges relating to tensions between infrastructural layers of IoT systems faced by design practitioners within the context of these commercial settings. Details of these challenges are explained before practitioners methods of addressing them through the use of notions of elemental states are discussed. The challenges and methods identified within these studies are compared and contrasted to current related literature to demonstrate how they build on existing knowledge. Analyses of the roles of data-work and professional plumbing are also presented here to extend current descriptions within the related literature. As a result of these detailed discussions, this chapter presents the conceptual contributions of this thesis and the implications of these for future research and practice, relating to the design of the IoT.

Chapter 8 - Conclusion The final chapter of this thesis summarises the work and presents the conceptual contributions generated as a result of this

[4]'notions of elemental state' is a term developed within this thesis to describe how members undertake a form of infrastructural inversion (Bowker, 1994). Drawing on a particular state of one or more infrastructural elements to explore their relationships; situating and supporting design reasoning work.

research.

1.5 Contribution statement

This thesis makes original contributions to understanding how IoT design work is achieved in practice. Contributions are made to CSCW and HCI through exploration and identification of IoT design challenges. The work extends current knowledge of infrastructuring in practice through the identification of various tensions surfaced as part of infrastructuring work. Additional contributions are made through demonstrations of the use of notions of elemental state and decision tree diagrams to maintain visibility over these relational elements. Contributions are made to HCI through building on current descriptions of IoT related data-work and the role of the digital plumber. The following sections summarise the contributions of this thesis as guided by the three research questions: 1) How do IoT related design teams organise their work? 2) What design challenges are being faced when designing for the IoT within a commercial context? 3) What design practices are being applied to IoT related design work within these settings and how?.

1.5.1 Identification of relational tensions within commercial IoT design

All three studies reported herein uncover design challenges resulting from tensions in the relations between the multifaceted sociotechnical layers of complex IoT systems. In particular, these have been identified here as existing between the hardware and software design approaches to permanence, between the technology and operational work processes involved in digital plumbing and between conventions of data work and user experience through a conversational user interface. Demonstrations are provided within studies II and III of how these tensions are surfaced through a process of infrastructuring as members make goals, values and potential states of different object universes and elemental layers visible through knowledge sharing and collaborative design reasoning activity. In this way, infrastructural inversion work (Bowker, 1994) can be seen in action.

1.5.2 Methods of maintaining visibility over and addressing relational tensions

From this use of infrastructural inversion as a generative design tool, notions of elemental state are constructed and used by members of these case study settings, (reported in chapters 5 and 6) to support design reasoning. These notions are surfaced using knowledge sharing and organised design tasks, then drawn upon to provide direction and anchor points for design work, to enable continual relation tracing between the elements in tension as the design work progresses. This builds on current understandings of both infrastructuring in practice (Simonsen et al., 2020) and IoT design processes (Lee et al., 2022) by demonstrating *how* practitioners uncover and draw upon relational tensions as a design resource within these settings.

Study III also demonstrates the use of decision trees as a method of maintaining visibility over product service infrastructures to support and situate design reasoning. In this case, decision trees are used to record and provide an overview of chatbot functionality in a similar way to the flows suggested by Shevat (2017). However, the team here had to engage in a process of *tailoring* decision tree diagrams to their project, thus providing them wider visibility over the entire infrastructure at hand. In this way they used them for more than just mapping chatbot functionality: they became a central resource to facilitate infrastructuring and data-work to help situate and anticipate customer responses to data insights. Thus, expanding on previous descriptions of data-work (Fischer et al., 2017) and its related challenges.

1.5.3 Expanding the role of the digital plumber

The final contribution of this thesis expands the digital plumbing role within the professional context beyond previous accounts (Tolmie et al., 2010; Castelli et al., 2021). The findings in study II demonstrate a digital plumbing representative as having a key role within the entire redesign process, from initially raising the trouble experienced during the field trials right through to executing and communicating the change to the engineering team. These findings build on the four major areas of digital plumbers work identified by Tolmie et al. (2010) as preparatory work, assembly of tools and parts, management of contingency and coordination and awareness. Due to the size of the design related responsibility demonstrated here an additional area of 'supporting the facilitation of change' is suggested.

Chapter 2

Literature review

Building on the literature discussed in section 1.1, this chapter introduces the IoT as a distinctive design space and demonstrates a gap in the research in relation to understanding *how* the unique design challenges within this space are addressed by practitioners. This literature serves to present a conceptual basis for the subsequent empirical studies of this thesis and to provide context to the research questions addressed herein. This review will first focus on a broader picture of the IoT before turning to HCI, CSCW, Ubiquitous Computing and Infrastructuring literature as a foundation and justification for the perspectives adopted in this research. The chapter is split into 3 core sections; 1) The IoT as a unique design space, 2) Design practice and 3) The infrastructuring perspective.

2.1 The IoT as a unique design space

As a nascent industry, the IoT is still developing its own identity, particularly within the design space. The multifaceted nature of IoT products and services means design must take a multidisciplinary approach incorporating stakeholders from hardware, software and data science backgrounds. While the industry is still growing, the IoT covers many different sectors and verticals. As this growth occurs new categories of IoT have been recognised and defined in order to differentiate the approaches, markets, and motivations of the systems. For example, Friedewald and Raabe (2011) describe the applications as covering; retail, industrial production and material management, transport logistics, personal identification and authentication, healthcare, mobility and transport. Ali et al. (2015) splits the applications into two broad categories of personal and enterprise, highlighting healthcare and smart cities as areas gaining traction. Other categorisations include; consumer IoT (Alladi et al., 2020), the industrial IoT (IIOT) (Boyes et al., 2018), and agricultural applications (Agri-IoT) (Kamilaris et al., 2016). The work within this thesis focuses on personal and enterprise IoT within a wide variety of sectors. It is important to note here, that due to this vastness and heterogeneity within the IoT, industrial, automotive, and smart city applications are not explored in detail within this work.

This section further explores the literature around the IoT design space, first considering structures and architectures before addressing design frameworks and the need to move beyond the lab to consider the embedded nature of deployed IoT.

2.1.1 Structures and architectures

The IoT is often thought of as a network of physical devices or 'things' which are embedded with sensors and software enabling them to collect and exchange data over the internet. Almost anything can be connected, classic examples include smart home devices, wearable fitness trackers, environment monitors and mobile phones. The data collected by these devices can be incorporated into a service layer to provide additional value to customers or can be used by businesses as an analytic tool to optimize performance, improve efficiency, and provide valuable insights into how people use them. The IoT is a growing industry which crosses almost all sectors and verticals. Key areas where a wide impact is being seen include;

smart homes (Desjardins et al., 2015), healthcare (Kashani et al., 2021; Darshan and Anandakumar, 2015), energy (Hossein Motlagh et al., 2020), agriculture (Ojha et al., 2021) and smart cities (Yin et al., 2015).

Within both academic and industry literature, IoT devices are often thought of and described with a focus on the technology layers (Kakkar et al., 2021), for example, as consisting of three layers (perception, network and application) (Sethi and Sarangi, 2017), or the four basic components of devices or sensors, connectivity, IoT platform and applications (Karie et al., 2020; Gokhale et al., 2018). Additional architectures have also been noted as including actuators (Sethi and Sarangi, 2017) and/or a service layer (Kakkar et al., 2021). In some fields there is a vision for the IoT that attempts to remove the human element altogether, and for a network of 'things' to communicate with each other somewhat independently. However, as researchers from a HCI, Ubicomp and CSCW background attest to, there is always a human interacting with it somewhere. Examples of human actors include; users, developers, data generators and engineers.

Due to their multifaceted nature IoT products and services have been identified as presenting unique challenges for designers, as they navigate new risk and value models associated with combining the different technological layers (Lee et al., 2018). Within the commercial context of new product development, Lee et al. (2019a) notes increased complexity in the design process of IoT products over that of purely hardware or software products. This is attributed to their *"multifaceted architectural and abstraction layers"* (Lee et al., 2019a, p.7). As a result, they suggest careful curation is required between design approaches of differing disciplines and a multitude of stakeholders. Adding digital layers to previously physical products (for example, a thermostat) changes the materiality to include both physical and digital experiences for the user. This fundamentally changes the requirements of the design work to include holistic design, as well as innovation at each individual architectural layer (Yoo et al., 2010).

The role of design teams is central to the creation of 'connected' devices and, due to the diversity of the growing IoT industry, skills are being adapted from multiple backgrounds and disciplines. This type of product design requires cooperation between very different types of design work. The combination of the physical and digital elements of smart products means that design teams must navigate, hardware design, software design and data science, all of which come from different conceptual backgrounds and as such, apply different goals, values, conventions and operational models to their design processes. Kuniavsky (2010) also noted the inclusion of industrial, identity, packaging and marketing design disciplines into the mix. In order to pull all this together into one cohesive experience for the user, it has also been suggested that a strong user experience element is incorporated (Burkitt, 2014; Rowland et al., 2015).

Within the business to business (B2B) sector, IoT solutions are often provided on a service basis with the devices and products remaining the property of the supplying business, with the purchaser paying ongoing subscriptions for the services they receive, sometimes referred to as product-service systems (PSS) (Askoxylakis, 2018) or servitisation (Rejeb et al., 2022). This places the onus of installation, maintenance and repair with the supplier and not the customer. There are often monitoring systems in place to alert customers and maintenance teams of scheduled repairs and breakdowns and to aid decision making (Voulgaridis et al., 2022). An important factor to consider here then, particularly in relation to commercially designed and deployed IoT, is the impact of these ongoing service aspects of IoT products. For example, additional management and maintenance work is often required by the supplying business. These aspects will need to be considered within any related design and modification work. In cases where the solutions are fully managed the work of professional field engineers similar to those discussed by Orr (1996) also becomes part of the service or product offering.

Traditionally design has focused on the initial release of a product and not concerned itself with the long-term maintenance elements. Indeed previous research around the differences between IoT design and traditional product design has also taken this approach (Lee et al., 2019a). Drawing on examples from related fields; Brand also alludes to this 'new' focus in his book on architecture, as he states *"the process of upkeep [is seen] as trivial, not part of design concerns"* (Brand, 1995, p.112). However, Suchman (1987) and Orr (1996) brought a different view to the fore. In their cases they were referring to the work of photocopier use and maintenance, presenting ethnographic studies as a way to better understand the material ways in which the work of maintenance is practiced and, particularly in Suchman's case, to put this forward as a crucial area in which to inform system design. The work of Suchman (1987) and Orr (1996), demonstrates the levels of complexity involved in incorporating a long-term maintenance perspective into design work that can be translated to the field of IoT. As business models move across to that of servitisation (Rejeb et al., 2022) with more and more product types included (for example, Rolls Royce aircraft engines), it becomes increasingly important for design practices to change to incorporate the concerns of the entire product life-cycle (Wong et al., 2008).

2.1.2 IoT design challenges, frameworks and guides

As with the IoT industry, academic literature around the IoT is fragmented and crosses many disciplines (such as, business, marketing, computer science, engineering, human factors, HCI and CSCW). As Vatsa and Singh (2015) point out, a large body of research in ubiquitous and pervasive computing concerns itself with research around internet connected technologies for sensing, tracking and monitoring human behaviour in some form. Liu et al. (2014) looked at how ubiquitous computing has been evolving and how the topics of focus have changed over time. They grouped the research from 1999 to 2007 and 2008 to 2013 based on a paradigm shift identified within their data from a keyword review. Design as a topic featured highly within both groups with a slight increase in popularity post 2008. Popular trends were identified as “evaluation” pre 2007 and “framework” post 2008 indicating a potential change towards informing and supporting design work. There are a number of “classic” challenges that have been central to Ubiquitous computing research since its conception, these include; context awareness (Lukowicz et al., 2011; Philipose et al., 2004), security (Campbell et al., 2002), energy efficiency and power, scalability, HCI, reliability (of data and operation), interoperability and communication (between the myriad of heterogeneous devices), and ethical implications (such as, privacy and consent). These research areas each highlight the complex and unique challenges that the IoT presents to designers and users as a result of connecting sensing technologies, data and software across the internet.

While, there is still a lack of research around the practices of IoT design, a number of models and frameworks have been suggested as a way to inform designers and businesses of essential concerns and requirements to be considered within the IoT design process. For example, Lee et al. (2022), present the ‘Mobius strip model of IoT development’ aimed at supporting design practitioners in better understanding how IoT systems should be developed as a NPD process. This also serves to provide a foundation for research in IoT design, an area where they note, a body of academic literature is yet to be established. The model itself offers a structure of development activities across the three core layers of hardware, software and data. This is structured as two continuous cycles, the first includes the hardware, software and data elements while the second is focused more on the data and software. This difference demonstrates the ongoing development nature of data and software which is in contrast to the physical form development. While this model provides a nice overview from a NPD perspective providing much needed contributions to a research gap, its core perspective is business related value models, as opposed to the HCI and

CSCW perspective taken within this thesis. A further limitation, which the authors themselves point to, is that it has been designed from a literature review of related work with no practitioners or design practice research incorporated to test or develop it.

Other work that has considered the layered nature of IoT as a challenge for designers is that of Rodden and Benford (2003). They discuss an architectural framework developed by Brand (1995) and how this influences the design of smart homes, specifically in the area of HCI research. The framework itself focuses on the home as consisting of layers that change at different rates. These layers include the site of the building, structure, skin, services, space plan and stuff. The suggestion from Brand is that these layers change at different rates with the site remaining static and the stuff changing continually. Rodden and Benford (2003) consider research in the area of ubiquitous computing in the home as falling within the 3 broad categories of understanding the domestic setting, research through design of devices and the creation of environments and underlying infrastructures. They consider Brand's framework in relation to the different stakeholders at play in making changes to the skills and roles required to execute changes at the different levels. Rodden and Benford make a distinction between ubiquitous computing research that focuses on the space plan and stuff layers and that which focuses on the service layers. The paper considers Brand's framework as something for ubiquitous computing to integrate with and consider.

The connected nature of the IoT and the incorporation of the data layer, raise key challenges in the areas of security and privacy. Due to their critical importance, these challenges are ones that have been considered in detail within academia, industry and policy. A wealth of guidelines, frameworks and best practice exist to advise practitioners of the risks and pitfalls of poor security and data protection. For example, the UK Government's Code of Practice for consumer IoT security (GOV.UK, 2018). These consist of 13 core considerations and are aimed at helping organisations to manage security and privacy risks. A further example is The IoT Security Foundation, a non-profit organization that aims to promote security in the IoT industry. They have also published a number of best practices guidelines for IoT design (IoTSF, 2016). These approaches to supporting IoT design practitioners are great in that they highlight key pitfalls and offer practical ways to address them through the implementation of specific design approaches and patterns. However, as with the other frameworks and guidelines discussed here they do not reflect the material ways in which these can be incorporated into the work of design in a practical sense as part of the collaborative naturally accountable order of design work as it happens.

Data protection legislation has also been working towards increasing the privacy and security of personal data within the IoT. For example, the general data protection regulation (GDPR) legislation brought in across Europe in 2018. While this legislation is designed to protect individuals rights in relation to data protection there are challenges regarding how it can be successfully implemented from a design perspective. Following a movement towards Human-Data Interaction (Mortier et al., 2014), some studies in ubiquitous computing have looked at how data accountability could be implemented from a practical perspective (Crabtree et al., 2018; Mortier et al., 2016) to give visibility and control to users. At the same time security by design approaches have also been gaining traction. This approach to design aims to build security into the foundation of a product or system from the beginning, rather than trying to add it later in the process (Atlam and Wills, 2020; Lam et al., 2021).

While these frameworks, guidelines and approaches address and highlight some important challenges that must be considered when designing for the IoT, there still remains a gap in the research around *how* IoT design is materially practiced within industry settings and therefore how these frameworks and guidelines can be successfully incorporated into an already complex design process. Thus leaving a potential theory practice gap unaddressed (Goodman et al., 2011).

2.1.3 IoT design as research

Within HCI and Ubiquitous computing research the motivation for designing IoT products is often either to test a new approach to one of the classic ubiquitous computing challenges (for example, testing an algorithm's ability to identify particular activities (Subasi et al., 2018)), or, more commonly within HCI, as a form of speculative design. For example, using design fictions (Hales, 2013) or cultural probes (Gaver et al., 1999); exploring the materiality of objects to investigate social impacts and adoption challenges of particular technologies within current or future scenarios (Nansen et al., 2014). As a research through design approach (Zimmerman et al., 2007) this often incorporates IoT objects as interactional prompts (Soro et al., 2018) or immersive experiences (Coulton et al., 2019). These prompts can either be used as a means to elicit reactions around technology use within future scenarios, such as in the living room of the future project (Sailaja et al., 2019) or to understand how a specific technology may fit into a particular problem space.

Additional approaches to this can also be seen in projects, such as, CharIoT (Fischer et al., 2017), where IoT technology probes were deployed to gain insights into how technology and data could support a specific activity or job role. While design challenges and recommendations are often uncovered within this type of design work their focus tends to be on the interactional side of the core users This differs somewhat from industry design work which requires a focus on the longer-term commercial viability elements of creating a product with ongoing software and service support.

2.1.4 Moving beyond the lab

It has been previously suggested that as embeddedness is core to the vision of ubiquitous computing it is important for research to move beyond the lab into real-world deployed settings (Fox et al., 2006). Building on this call for more real-world research and the challenge of seamlessly embedding 'things' into domestic settings, Tolmie et al. (2010) considered the installation of devices within these environments, referring to the mundane work of digital plumbing. In their reporting of researchers deploying a prototype into a real home they shed light on the mundane nature of this work and the need for design work to support it. Grinter et al. (2009) presents the view of this installation and maintenance work as something which is often required of household members. These papers highlight the need for systems to both support the social order and evolving routines of the environment in which they are being embedded as well as those of the person doing the installing.

Thus, there is a need to consider the concept of digital plumbing (Tolmie et al., 2010) as extending beyond the work of researchers and householders (Grinter et al., 2009), to also include professional engineers. Castelli et al. (2021) has recently begun to examine the work of professional digital plumbers through ethnographically unpacking the installation work of an IoT based energy management system within a large business. They highlight complexity in stakeholder roles and relations as a key focus for research moving forwards. However, as with the other papers discussed here, their focus remains on the initial installation work to get the system set up. There is little consideration for the ongoing collaborative work required in maintaining, managing and expanding these solutions within the current notion of the digital plumber's role as a sociotechnical part of an information infrastructure and as a type of user.

The move beyond the lab within the field of ubiquitous computing has presented challenges of embeddedness and invisibility-in-use as central features within IoT design, through investigations into deployed systems from a user perspective. However, again, there has been little focus on the perspective of the designer, in particular *how* IoT design work is materially practiced within industry environments. For example, methods used by practitioners to address and navigate these core challenges within industry contexts. A further challenge facing commercially based design teams, that is often missed within research based prototype studies, is that of modifying existing commercial systems that are already deployed, i.e., moving beyond the view of initially embedding a thing to also consider the evolving nature of systems and routines.

2.1.5 Summary

IoT products and services are complex sociotechnical systems, comprised of multifaceted layers and embedded within physical environments and social structures. From a HCI perspective they intersect with a diverse collection of humans in use, as a commercial entity and as part of the design process itself. Previous research into designing IoT products and services has looked at addressing specific challenges and has suggested structures and frameworks for design. However, there is still a need remaining for this research to move beyond the research deployment to address the gap in understanding the material realities of design practice within this field, so as to better support the commercial work of design.

2.2 Design practice and studies of work

Design practice and studies of work have a rich history within the fields of HCI and CSCW. There is however, little in the ubiquitous computing literature to this effect. The following sections will outline some of the history of design practice research to situate and ground the work reported in this thesis.

2.2.1 Studying design practice

The work of design is often considered in terms of cognitive or work processes of individual designers (Coley et al., 2007; Dorst, 2011; Kim and Ryu, 2014). Bucciarelli (1988) criticised many of the traditional approaches of looking at design as a purely mechanical process, and highlighted the social aspects of professional design work. From two ethnographic studies of engineering design he concluded that contributions to design are made by many different people both inside and outside the organisation. The process observed was not just constrained to creative engineers. He also noted how different design backgrounds within the design process framed design in different ways. He used the example of an electrical and a mechanical engineer, stating that when looking at the same object these people will be framing it differently. In addition to the backgrounds influencing views and approaches to design, Schon (1983) also stressed the difficulty and impact of working within an *"organisational knowledge structure"*. Noting that the context the designer is working within will influence the ways in which they work and the processes used to achieve their goals. In this way design can be considered as embedded within the sociotechnical context of its production.

Schön also notes the individual aspects of the work as he talks about the reflective practitioner problem solving design challenges through the use of hypotheses testing. This also resonates with the work of engineers described by Orr (1996) in relation to the problem solving work of photocopy maintenance engineers. Another interesting area of Schön's work relates to the difficulty practitioners have in describing what is involved in a skill after it has been mastered. Thus arguing a case for observational studies as a way to fully understand the work practices, rather than practitioner accounts, such as interview responses. The work of Bucciarelli and Schön highlights the importance of considering design work as a social process situated within a wider context rather than just the individual designers that make up the design team.

Pycock and Bowers (1996) conducted an ethnographic study of design practice within the fashion industry that supported Bucciarelli and Schön's findings. Their study looked primarily at the work of garment technologists for a large mail-order fashion retailer. They highlight the importance of complex relationships both between departments within the business and with external manufacturing suppliers in the work of fashion design. Interestingly they also note that design related activities within this setting are often not referred to by the members as coming under the heading of 'design'. Instead the work was considered as the tasks it entailed, such as 'product specification'. Much of the design work was cooperative and contained both planned and spontaneous collaboration. With spontaneous collaboration more likely to occur when working on solving specific problems. Martin et al. (2009); Martin (2012) found something similar to this when they looked at the work of graphic designers within a small packaging design agency. They described this type of design work to be *"inherently social"* through a mixture of planned collaboration activities and spontaneous interactions. However, the talk identified in this study was more heavily focused on the aesthetic elements of the project rather than the focus on technical detail seen in Pycock and Bowers' work. This difference in focus could be due to the type of products, organisation and designer backgrounds influencing the initial framing of the design task.

An in-depth ethnographic case study as part of a UX design team within a large company, was conducted by Lodato (2015). The findings discuss the difficult relationship between marketing requirements, engineering and UX design work. Implications of changes on the work and the requirements of other teams was a challenge particularly between the UX team and the engineers. These difficulties were accentuated due to recent changes in the company structure. The business was traditionally engineering focused and had recently brought UX design into their product development process.

Lodato highlights the collaborative challenges faced between different types of designer. A challenge that resonates with the object worlds discussed by Bucciarelli (1988), in that a designer's background can frame design work and influence their approach. While this difficulty may have been overly accentuated due to a recent change within the business, it supports the observations of Leiva et al. (2019) where tensions arise as part of multidisciplinary design projects.

2.2.2 The turn to practice in HCI and CSCW

By taking an ethnographic approach to study the sociotechnical work of industry practitioners, this thesis contributes to the practice-oriented program of CSCW (Schmidt, 2009). Investigations of collaborative work practice make up a large body of ethnographically informed CSCW research contributing to technological research and development and spilling over into the neighbouring fields of HCI, Participatory Design (PD) and Science and Technology Studies (STS). Classic examples here include air traffic control (Bentley et al., 1992) and London Underground studies (Heath and Luff, 1992). Kuutti (2013) also notes that studies of practice informed by ethnomethodology, as the case studies are in this thesis, have been influential in defining the research agenda of the European arm of CSCW research. He does however, present some criticism of the practice theory field in relation to difficulties in finding meaningful ways to discuss the use of artifacts as a significant part of the work and a tendency to look at stable situations. Thus avoiding the difficulty in discussing and analysing dynamic factors of change and developing practices. Nevertheless, while there may be short-comings of practice studies in general, it is widely acknowledged as a necessary and valuable contribution to the fields of both HCI and CSCW. This approach has not gained as much traction within the Ubiquitous Computing field, however, the strong crossovers with HCI and the lack of literature around the field of IoT design, justify the approach as appropriate in this case. The design practice and studies of work approach taken in this thesis is consonant with a broad 'turn to practice' in HCI (Kuutti and Bannon, 2014).

As with many scientific disciplines it is believed that HCI has a research-practice gap. This has been discussed by a number of researchers in the field. For example, Norman (2010) argues that a gap exists and that it's due to differing skill sets and motivations between the two groups (academics and professionals). He suggests that translation work is needed to bridge this gap. This involves taking insights from academia and translating them into usable form in the practical sense, and equally translating challenges from practitioners into research insights within academia. He does not however, offer much in the form of direction on how he thinks translation work should be approached. Goodman et al. (2011) also discuss this gap. They suggest that to investigate the existence and extent of a theory-practice gap we need to take a closer look at how interaction designers within the commercial world actually work, how their roles are organised and what constitutes professional competence.

Gray et al. (2014) conducted a series of interviews with interaction designers relating to their knowledge and use of specific methods. From their findings, they put forward a model of "bubble-up" (transfer of ideas from practice to theory) and "trickle-down" (transfer from theory to practice). The choice of terminology here notably has some hierarchical connotations that potentially corresponds to a more traditional way of thinking about the links between the two. They discuss the current relationship between theory and practice as difficult due to researchers putting time and energy into developing theory and methods that are not adopted by practitioners. They suggest that this disconnect may be related to the communication channels used in academia being different from the channels being absorbed in practice. However, this could also be related to the methods not being developed with a thorough understanding of the organisational context in which is it designed to be used. They propose that design practice should be looked at in more detail to understand the how practice is actually carried out in situ.

Another study by Dickson and Stolterman (2016) supports this. They evaluate the extent of the theory-practice gap through a series of interviews and observations with practitioners, academics and academic-practitioners. They found that the most successfully adopted user-centered design (UCD) methods were ones developed by 'the academic-practitioner'. They reflect that one of the common failings of method developers is not taking the approach that the design practitioner, who will be using the method in their working practices, is in fact a 'user'. The paper suggests that user-research should be incorporated into the method development and that UCD should be central to the development of UCD methods. They argue that academics face difficulties in developing methods if they lack a good understanding of the design practitioners' perspectives.

These studies highlight the need for more research into the work of design practice. This would provide insight into the work of the 'users' (i.e., design practitioners) that methods and frameworks are being developed for. As noted earlier the IoT is a unique design space that differs from traditional design settings, and where there is currently a lack literature (Lee et al., 2022), particularly in relation to studies of design practice.

2.2.3 Summary

In summary then, ethnographically informed work practice research is an important contributor to both HCI and CSCW fields. To date there have been some very influential studies that have helped to steer the discipline particularly within Europe. Work practice studies are well placed to inform technology design through detailed insights of the natural accountability of work within specific settings, such as air traffic control (Bentley et al., 1992). However, to date these have not been adequately represented within the fields of IoT and Ubiquitous Computing. The work of this thesis in unpacking design practice within the under researched field of IoT design can inform practitioners and researchers looking to support the work of design in this field. Proving insights to inform technology and process design, helping to identify and close research-practice gaps within HCI and the IoT.

2.3 The infrastructuring perspective

CSCW has long had a conceptual and practical interest in notions of infrastructure (Karasti and Blomberg, 2018). This section reviews some of this work to situate the thesis' concern for infrastructuring. Firstly explaining the basic conceptual foundations of working with information infrastructures, before discussing infrastructuring as an approach to design, including the use of infrastructural inversion to navigate the core challenges of working with information infrastructures.

2.3.1 Infrastructuring as an approach to design

This thesis draws on conceptualisations of information infrastructures as sociotechnical and relational in nature. Neumann and Star (1996) are credited with introducing the notion of sociotechnical information infrastructures to the field of design. Their work reports on the development of a digital library system commissioned by the US government. Drawing on the field of STS and previous works (Star and Ruhleder, 1994, 1996), they highlight the relational nature of infrastructures and the levels of complexity involved in infrastructural work. Through this Neumann and Star present a view of information infrastructures that looks beyond the object view to consider the relationship of infrastructural elements to people and activities. They drew on Bucciarelli's notion of object worlds (Bucciarelli, 1988), as a central concept impacting participatory design, with a focus on bringing together object worlds as object universes (Neumann and Star, 1996). As noted earlier in this review, Bucciarelli (1988) suggested, particularly within organisational design settings, participants often come from very different 'object worlds', which incorporate the knowledge, tools, processes and cultures associated with their disciplines, departments and job roles. He argued design participants coming from different object worlds approach and see the design differently. It is important to note that for Neumann and Star, infrastructure is situated, i.e. something that happens for someone at a particular point in time. Thus, when considering the sociotechnical aspects of design work, the diversity of infrastructural elements and actor backgrounds, presents additional challenges to the complexity of the design task.

Building on Star and Ruhleder (1996), Star and Bowker (2006) specified 8 salient features of infrastructure. These include; embeddedness (in structures arrangements and technologies), transparency (invisibly supporting tasks), reach or scope (beyond a single event or practice), learned about as part of membership (gaining familiarity), links with conventions of practice (shaping and being shaped by practices), embodying standards (plugging-in in a standardised way), built on an installed base (inheriting strengths and limitations) and becoming visible on breakdown (emerging from their invisible state). These salient features provide a sense of the enormity of information infrastructures within the modern connected world and offer a way to help conceptualise and ground our understanding of the related design work or 'infrastructuring' involved in working with them. One of the core concepts differentiating infrastructure building from 'object design' is the concept of working with the installed base, something Neumann and Star (1996) referred to as one of the greatest challenges. Their work suggests concepts of embeddedness within an installed base and invisibility-in-use both pose significant challenges for design work, as by its very nature design relies on an element of visibility over its subject. In addition to this, infrastructures need to be able to persist in time, therefore the work of modification is key (Star and Bowker, 2006). Star and Ruhleder (1996) suggest infrastructural inversion as a potential way to address these core challenges.

Infrastructural inversion, as introduced by Bowker (1994) and expanded on by Star and Ruhleder (1996) involves intentionally changing the focus from people and 'things' as the cause of change to also include relations. This change in focus allows the foregrounding of elements usually residing in the background. Thereby attending to such things as the mundane, the routine and unnoticed supporting work that enables the infrastructures to function, such as software algorithms, standards and processes. Infrastructural inversion was traditionally used by researchers looking to uncover infrastructural invisibility for research purposes. More recent views on infrastructural inversion have expanded this notion to include gaining purchase for design from the visibility created in breakdown situations (Pipek and Wulf, 2009) or through incorporating stakeholders for whom infrastructuring is part of their everyday work (Parmiggiani, 2015). While initially this approach was about researchers understanding the nature of the infrastructure, more recently it has been considered as a method used by participants of the setting being studied (Parmiggiani, 2015) and suggested as a generative approach to design (Korn and Voida, 2015; Simonsen et al., 2020).

The work of Pipek and Wulf (2009) draws on infrastructuring as a way to conceptualise organisationally based IT solutions, thus focusing on ongoing design challenges within the workplace. They refer to work infrastructures to consider the complexities of these systems and the ways in which physical systems are embedded within social infrastructures. Their framework refers to 'points of infrastructure' (moments when the infrastructure becomes visible to the user due to breakdown) which subsequently support a search process leading to design activity or innovation. This results in changes to the work process, technology or both. While the work of Pipek and Wulf is useful for expanding the view of infrastructuring and providing insight into the creative processes that lead to change, their descriptions of the design work itself are fairly general with little detail on how the work is practically accomplished beyond the point of infrastructure—a limitation that Bødker et al. (2017) also alludes to. A particularly interesting point about Pipek and Wulf's approach, however, is their take on the human element, with actors seen as both a creative resource driving change and an infrastructural element. By this we mean that the knowledge-bases, work practices and related resources relied upon to achieve assigned tasks and goals are all considered as part of the infrastructure. Bowker et al. (2009) also specifies individuals within related roles such as designers, developers and users as being included as elements under the conceptual banner of information infrastructures.

Much of the research on information infrastructures relates to researchers working with information infrastructures such as, online library systems (Neumann and Star, 1996), work infrastructures (Pipek and Wulf, 2009; Simonsen et al., 2020), infrastructures of civic engagement (Korn and Voida, 2015) and oil and gas suppliers (Parmiggiani, 2015). While elements of the internet of things (IoT) feature as parts of these infrastructures (for example, the smart-boards discussed in Simonsen et al. (2020)) in that technology change influences and embeds into social process, there is a lack of research looking at how this features within the IoT industry itself, in particular, *how* infrastructuring as a process supports the work of technology design and development within this domain.

2.3.2 IoT systems as sociotechnical and relational

It is notable that many of the design challenges of interest to HCI and CSCW in relation to the IoT or more specifically Ubiquitous Computing, are in line with those discussed in the infrastructuring discourse. Since

Weiser's vision of 'invisible' computing (Weiser, 1991), much of the focus of this area of research has been on the capabilities, opportunities and limitations of the technologies themselves (Gubbi et al., 2013; Patel et al., 2017), regarding the embedding of technologies into the home environment and domestic routines (Crabtree and Rodden, 2004; Soro et al., 2018), use and privacy of data (Fischer et al., 2016; Lodge and Crabtree, 2019) and that of user interactions with domain specific devices (Brereton et al., 2015). The design insights presented within these areas of research all allude to challenges of embeddedness, links to practice, working with installed bases and (in)visibility as core within IoT design settings.

Tolmie et al. (2002) delve into the challenge of invisibility-in-use within domestic settings and discuss ways in which ubiquitous computing can be embedded seamlessly and naturally into users' routines. They discuss a design focus on augmenting resources available to action as part of routines as a way to achieve this invisibility-in-use and note that care must be taken so as not to disrupt the routine that is being supported. Dourish (2004) builds on this noting the relational aspects between physical infrastructure and activity. His paper suggests context is a central issue for ubiquitous computing design and highlights challenges relating to both its situated and relational nature. These papers further elaborate on the core IoT design challenges of (in)visibility and embeddedness and suggest areas for designers to focus their attention. They do however, alongside much of the Ubiquitous Computing literature, place their emphasis on the initial design of a product and the related considerations for designers looking to embed a 'thing' into the domestic setting.

2.3.3 Summary

Information infrastructures are situated, sociotechnical and relational in nature. The work of designing infrastructures (infrastructuring) goes beyond that of object design as practitioners need to navigate their embeddedness within an installed base along with their invisibility-in-use (Neumann and Star, 1996). Challenges which are notably also apparent within IoT design, as reported in the Ubiquitous Computing literature. These complexities of information infrastructures present significant design challenges, which can potentially be addressed through a process of infrastructural inversion (Bowker, 1994). Infrastructuring literature has considered design practice within a number of contexts, some of which feature IoT products as embedded into social processes. However, research in this area is lacking in relation to *how* infrastructuring as a process supports the work of IoT design.

2.4 Chapter summary

Building on the discourse around infrastructuring, IoT design challenges, design as a social endeavour and the broad turn to practice (in HCI and CSCW), this thesis takes an ethnographic approach to understanding the work of practitioners within the commercial field of IoT. As this literature review has demonstrated, gaps exist in these various bodies of literature, around understanding the challenges of IoT design and in particular, design practice. The IoT itself is a unique design space that differs from other, well studied, design domains. The additional challenges in relation to multifaceted layered nature and the complexity of stakeholder relations makes this an important area in which to unpack the practical accomplishments of designers in order to feed into the emerging collection of tools, frameworks and methods being developed to support the work of design within this context.

Chapter 3

Methodological approach

3.1 Chapter overview

This chapter provides explanation of the methodology and practicalities of the empirical investigations reported in this thesis. The research aims of the three studies seek to gain an understanding of the challenges and practices of designers working within the commercial IoT to unpack the organisation of the work itself as a practical accomplishment. This is achieved through a mixed set of methods selected specifically to support the goals of each of the studies. This chapter will first present the global approach to addressing the research questions, followed by details of the approach to the industry overview in study I (chapter 4), and then the ethnographic approach to studies II and III (chapters 5 and 6). These descriptions include the practicalities of the approaches along with the methodological configurations and justification for each.

3.2 Global approach

This thesis takes a QUAL-qual mixed methods approach to addressing the research questions outlined in the introduction (Morse, 2010). In this context mixed methods can be defined as:

> "Mixed method design consists of a complete method (i.e., the core component), plus one (or more) incomplete method(s) (i.e., the supplementary component[s]) that cannot be published alone, within a single study". - (Morse and Niehaus, 2009, p.9)

Three empirical studies make up the remainder of this thesis as an exploratory investigation into industry based, IoT related design practice. Study I (reported in chapter 4), offers an industry overview obtained through informal exploratory ethnographic fieldwork at various industry events, followed by a data-driven thematic analysis (Boyatzis, 1998) of 11 semi-structured practitioner interviews. This informal ethnography provided background industry knowledge for the researcher, while the interviews provided a general overview of design challenges within the IoT industry. Both served as 'supplementary components', to situate and underpin the subsequent formal fieldwork studies. From this 2 fieldwork contexts were specifically selected to allow deeper dives into some of the identified challenges, to unpack the everyday self-organised nature of the design practices being applied to IoT projects.

These two detailed ethnographic case studies (reported in chapters 5 and 6), use an ethnomethodolgical approach (Garfinkel, 1967) to unpack members' methods in the doing of IoT design work (Crabtree et al., 2012). These case studies serve to provide detailed insights into design practices with a focus on the naturally accountable phenomena of design challenges encountered. The ethnomethodological approach builds upon the industry overview through detailed accounts of the machinery of interaction (Sacks,

1984) that makes up the work of design in this context. Thus it provides implications for design of tools, processes and methods to support these identified practices (Crabtree et al., 2012). The ethnomethodological approach is widely used within the HCI and CSCW research and is particularly suited to *"the study of complex organizational environments"* (Randall et al., 2021).

These two selected methods of enquiry compliment each other in that, interviews can offer a broad perspective of a phenomena across a variety of settings in a relatively short period of time. This is then complemented through the in-depth longer-term approach of the ethnographic case studies, in unpacking the material practices of commercial IoT design. Interviews have been presented as a way to uncover a persons conceptions and *"'imagined' meanings"* of activities and events (Lamont and Swidler, 2014), drawing out moments that resonate in a person's memory as significant and therefore reflections of their categorization systems. Thus, they can provide rich descriptions of design challenges that participants have faced. There are however cautions to be considered around the limitations of interviews, particularly for this case, in how to contextualise these challenges within the *"relevant features of institutional contexts"* (Lamont and Swidler, 2014). Within this thesis the interview study is designed to provide an overview of challenges from which to delve deeper through the use of ethnomethodologically informed ethnography (Garfinkel, 1967; Crabtree et al., 2012). Through this, the indexical and reflective nature of the challenges to their institutional context are then incorporated within the latter study chapters as a natural part and parcel of this immersive approach. Thus, the global approach to combining these methods provides a more holistic view of the problem space of IoT design practice by situating the more focused case studies within the wider context. Thereby, supporting the exploratory aims of this research. Further details of these methodological approaches will be provided later in this chapter.

From a practical perspective; the studies were approved by the University of Nottingham computer science ethics committee. As such, consent forms information sheets and data privacy documents were provided to participants prior to any data collection. Where data related to fieldwork within a business environment senior members of staff were initially approached for consent. Following that, each member of staff involved in the data collection was also given this information and the opportunity to opt out was highlighted. No-one chose to do this. The data collected across the three studies comprised field-notes, audio and video recordings. In addition to the ethics documents, legal documents were also required to gain access for recording sensitive business information within the commercial environments. Further details of the access challenges and process will be discussed later in this chapter.

3.3 Ethnographic approach to industry overview

The ethnographic approach to the industry events section of the industry overview chapter, reported in chapter 4, was used to generate rich descriptions of the events themselves. The approach to the ethnography in this section was informal and involved attendance at the events as an open interested party for the purpose of research. The aim of this was three-fold; firstly, it was a knowledge generation exercise for the researcher. This allowed her to build on background knowledge of a professional career in user experience within the web and app industry, expanding into the field of the IoT. This knowledge could then be used to better design and understand the relevance of the subsequent data collection through interview and ethnographic fieldwork studies. This background knowledge building provided a basis for the for the development of 'vulgar competence' [1](Garfinkel and

[1]Vulgar competence refers to the researchers ability to see and understand the world from the perspective of the members of the setting to enable a 'unique adequacy' in the recognition and unpacking of the in the ordinary affairs of the setting under study to the same degree of recognition as the setting's members have (Garfinkel and Wieder, 1992).

Wieder, 1992) within the full ethnographic case studies reported in chapters 5 and 6. Secondly, this approach to immersion within industry events provided an additional platform from which to recruitment interview and fieldwork participants. Finally, this produced rich descriptions of the events themselves as part of the IoT industry, providing representations of events that are attended and organised by practitioners working within the field.

3.3.1 Event selection and data capture

A number of industry events were attended as a form of initial scoping fieldwork. These events were identified through social media channels and through a snowball approach, via various newsletters from previously attended events. A broad range of events were selected to attend, based on their size, location and subject areas. The selection included events which were focused on IoT along with broader events that included an element of IoT, but where this was not the main focus. For example, IoT Tech Expo and Eco Build Show were both attended. These were events of similar sizes. The IoT Tech Expo was heavily IoT focused and therefore featured mainly IoT businesses. In contrast, the ECO build show included non-IoT business such as, extractor fan companies that had developed IoT products within their range. Chapter 4 provides a full list of events in table 4.1 along with descriptions of the format, structure and content of the industry events attended as part of this research. In addition to the scoping fieldwork approach to these events, they were also used as a platform to recruit participants for the empirical studies reported in this thesis.

Data capture from these events was achieved though immersion into the events as a visiting party involving; observing talks, visiting company stands and engaging in informal conversations with practitioners about their products, work and practices. Field-notes were collected alongside

The background knowledge gained within the industry overview chapter was therefore carried forwards by the researcher to inform the deeper diver into practitioners' methods.

documentation in the form of event programs and product marketing materials. This data was then filtered and written up as descriptive accounts of the events.

3.4 Interview approach to industry overview

In seeking to address RQ2, the interview questions focused on descriptions of projects that participants had worked on including the challenges they faced and design methods used. This ensured that participants stayed focused on their experience of design work rather than their opinions of design generally and what constitutes IoT, although these topics did inevitably come up from time to time. The interviews were then transcribed and a thematic analysis approach was applied to the data in order to identify and present the core challenges for the purpose of reporting in this thesis.

3.4.1 Access challenges

In total over 150 businesses were approached about taking part in the interview study, 23 of these agreed to interviews regarding their design process. Subsequently, 12 of these fell through for various reasons including; changes of circumstances, time constraints and concerns over divulging confidential information. In many cases the communication channels with the participants just dried up, with no reason given. Often this occurred after a more detailed chat about the aims and objectives of the research. However, on a few occasions comments were offered as reasons for the change from acceptance to refusal such as, *"we don't really have IoT project processes"* and *"I couldn't get the approval"*.

During the recruitment process a general trend was noted in relation to a particular reluctance from designers and engineers to discuss their own processes. In contrast, owners, directors and founders were much more keen to talk, particularly those from smaller businesses and startups where they had broader involvement at a project level. In general employees from larger companies were cautious about what they could and couldn't share due to commercial sensitivity and often backtracked after consulting with their manager. On a number of occasions direct access to the manager was requested, however, this was mostly refused.

3.4.2 Data collection

Where possible interviews were conducted contextually within the participant's place of work. In total 7 were contextual interviews and the remaining 4 were conducted remotely, via video calls, due to logistical challenges and participant preferences. Where this was done remotely the relevant ethics documents were emailed over to participants and completed forms were emailed back before the interview. In these cases additional checks were also made before the recording commenced to confirm they had read and completed the consent form.

All participants had self-reported previously being involved in design elements of an IoT related project. The interviews were conducted using a semi-structured approach, this involved allowing participants to talk as much or as little as they wanted around the design process, team structure, resources, approaches and challenges. Space was given to allow some divergence from these topics to allow the conversation to flow in directions that participants were interested in or passionate about. Where information began to be repeated or the topic was deemed by the researcher to have gone too far off track, prompts were used by the researcher to steer the topic back to the organisation of design work, including, challenges encountered and approaches used within the project. Interviews lasted around 45 minutes, depending on how much the participants had to say. Audio data was collected using multiple recording devices whilst on-site. For remote interviews QuickTime player was used to screen record (audio only). Data was transcribed and coded using a thematic analysis approach.

3.4.3 Thematic analysis approach

Thematic analysis is a popular method in which variations of approaches exist. It is used across a number of disciplines, particularly those which relate to the social sciences, including HCI (de Carvalho and Fabiano, 2021; Brown, 2018). While it can also be used as a theory-driven approach (Clarke and Braun, 2013), which is popular within fields such as psychology, the work in this thesis is based on a data-driven approach (Boyatzis, 1998), with the acknowledgment that the researchers orientation to the data is inherently linked to the research questions being addressed (Lochmiller, 2021) (i.e., in this case uncovering the challenges and processes of IoT design work in practice settings).

Thematic analysis can be described as a method of identification and analysis of patterns in a qualitative data corpus (Boyatzis, 1998). It is an analytic method independent of theory, that involves pattern matching, encoding and interpretation within qualitative data (Clarke and Braun, 2013) in relation to the research question. This approach provides rich descriptions of collected data in a form that is understandable, that can be used to inform subsequent empirical enquiry.

> “During the pre-discovery, ‘fuzzy’ stage of formulation of a research agenda, thematic analysis enables the researcher to access a wide variety of phenomenological information as an inductive beginning of the enquiry” (Boyatzis, 1998, p.5)

This makes it an ideal approach to include within the industry overview section of this thesis, with an intended purpose of informing and guiding the direction of the subsequent case studies. Themes and sub-themes are presented in chapter 4, which are then carried forward through the site and project selection decisions applied to the fieldwork case studies presented in chapters 5 and 6.

3.4.4 Thematic analysis process

In the case of this thesis, data collection and analysis was iterative, starting with 8 interviews and building up from there until a total of 11 interviews had been conducted, audio recorded and transcribed. Transcription was conducted manually, in parallel to data collection, as an early opportunity to delve into the data as suggested by (Braun and Clarke, 2006). Grammar and syntax were improved to enhance readability through denauralisation during transcription (Oliver et al., 2005). When a point of saturation was reached with responses becoming repetitive, data collection was discontinued. A data-driven thematic analysis approach (Boyatzis, 1998) was then applied to the transcripts. NVivo software was used to assist with coding the corpus and generating themes. The subsequent encoding of the data resulted in a list of directly observable themes relating to IoT design challenges (reported in chapter 4). As Boyatzis (1998) explains:

> *"A theme is a pattern found in the information that at minimum describes and organises the possible observations and at maximum interprets aspects of the phenomenon"*- (Boyatzis, 1998, p.4).

Themes are generated through a process of code development. The initial stage of code development involves paraphrasing and summarising the collected data retaining relevant information that the researcher deems important to the research question. This process allows the researcher to really get to know the data with a high level of familiarity throughout. Themes are then identified during the second stage through the identification of similarities or patterns within sub-samples. Comparisons of themes are made between sub-samples before themes can be converted into codes. This is done through the construction of statements of differentiation between sub-samples. In this way, labels, descriptions, indicators and examples are constructed and collated. Following this, codes are applied to the full dataset with themes organised conceptually to form theme clusters and hierarchies (Boyatzis, 1998). A thematic report can then be produced to communicate the results clearly.

3.5 Ethnographic fieldwork - case studies

Building on the industry overview and following on from a rich history of work practice studies within HCI and CSCW, two ethnographic fieldwork sites were selected as suitable locations for deeper dives into the challenges of commercially situated IoT design work. This section describes the approach taken to recruitment, access, data capture and methodological orientation.

3.5.1 Recruitment and access

A number of different methods were attempted for recruitment of appropriate fieldwork sites. These included known connections from a previous life as a UX practitioner, connections from the supervisory team, wider networks through a snowball approach (i.e., connections of connections), social media requests, direct approaches to business representatives at industry events as well as cold emails and website contact forms to local businesses.

As a result of these connections and approaches, detailed conversations were had with 14 businesses, all with ongoing IoT related project work, regarding the potential of conducting ethnographic fieldwork within their place of business. Of these initial positive responses 10 resulted in meetings to discuss practicalities. While most of these discussions were positive in nature, moving to the next step proved difficult and businesses either stopped responding, postponed indefinitely, could not offer access within the project time-frames or changed their minds after further internal consultations. For example,

> *"We had a discussion internally on Friday regarding your project and I am afraid I couldn't get the approval due to the number of projects that we are working on at the moment. Sorry for any inconvenience caused."*

> *"[We] are going to be very busy for the next few months, so will not be able to meet with you. Please get back in contact in a few months and we can reassess availability."*

> *"I've had a discussion with my colleagues and we are struggling see how we could support you for your project. We are already aware that we don't really have IoT project processes, what we are doing is not working as good as it should and so we are actively developing our processes ourselves."*

In the end 3 businesses agreed to fieldwork within the required time-frames of the project. Two were selected for this thesis and the third was discounted by the researcher due to the size of the business being just one person. Once sites had been selected, gaining access to begin fieldwork presented a number of additional challenges and delays to this research. A particular challenge here was that of legal documentation to ensure confidentiality due to the sensitive nature of commercial product design. Both fieldwork sites presented this as mandatory, WISP, as a smaller business, requested this was drawn up by the University, while LEC, as a large corporate, required this to be generated by their own legal team. The two timelines presented in figure 3.1 and 3.2 demonstrate the process and associated time-frames from initial contact through to fieldwork commencing.

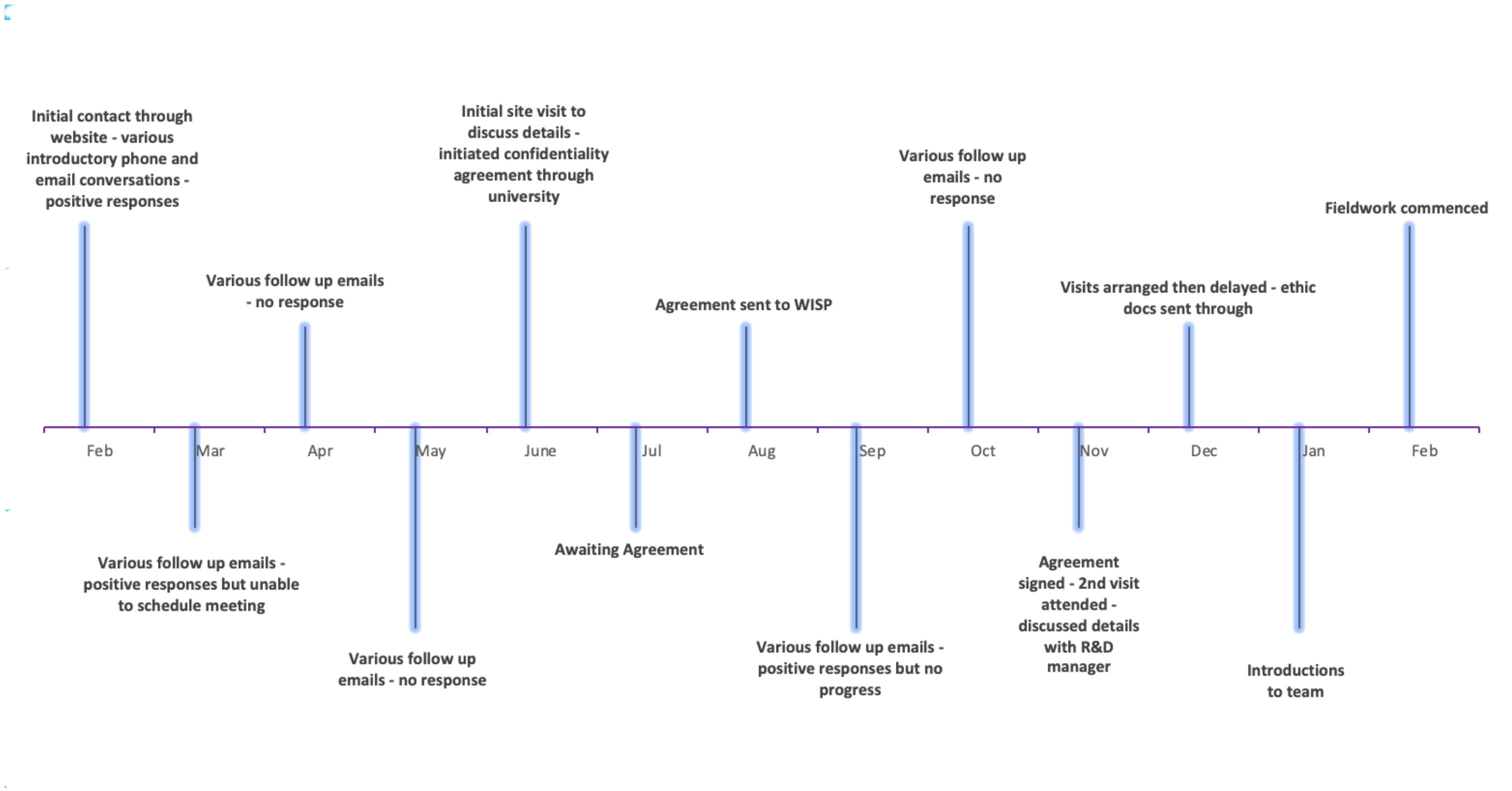

Figure 3.1: Timeline for access to WISP fieldwork

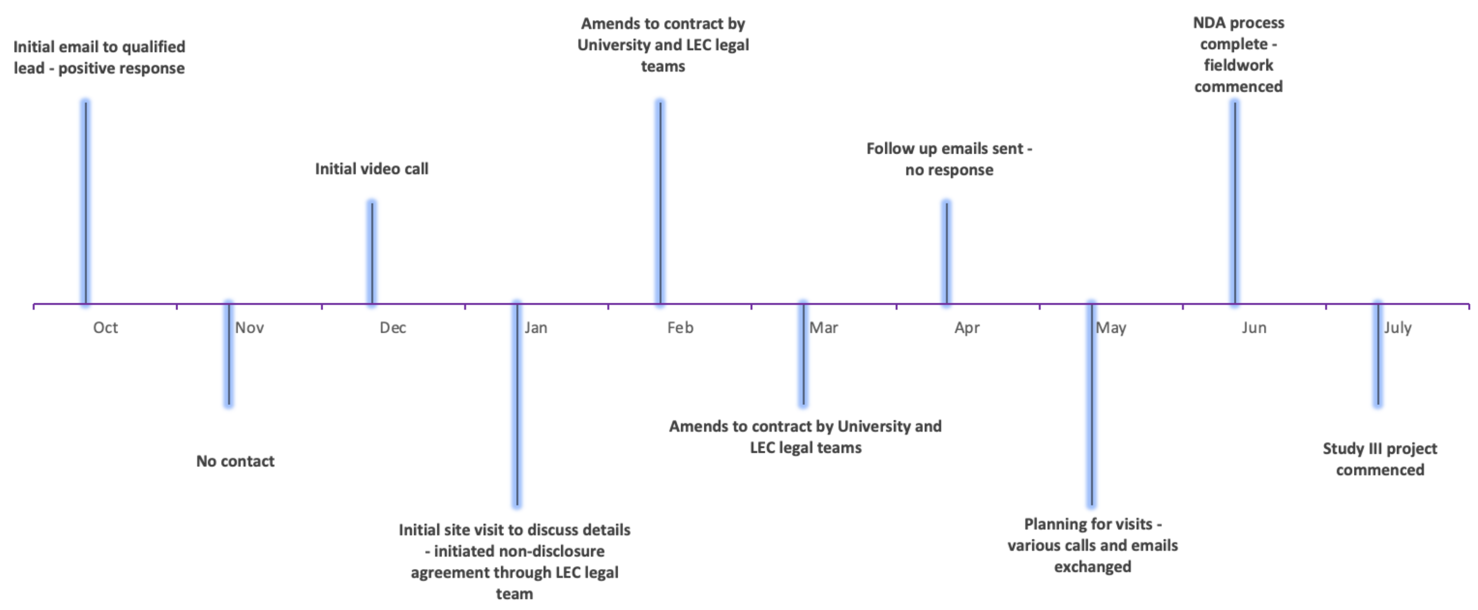

Figure 3.2: Timeline for access to LEC fieldwork

3.5.2 Data capture

The ethics process, agreed by the University of Nottingham computer science ethics committee, involved all members of the R&D teams giving informed consent, additional employees were also asked for informed consent as and when data collection overlapped with other departments due to project based interactions. Each of these employees were presented with data privacy information, an information sheet detailing the research and a consent form to sign should they wish to take part. Participants were advised that taking part was optional and that they could request their data be withdrawn at any time. They were also able to opt out of the different forms of data collection if they wished. None of the team members opted out of the study itself, or of any of the data collection options presented to them. All data has been anonymised prior to reporting in this thesis through amending the members' and company names. Due to the importance of understanding participant's roles within this work, gender and job roles have not been changed. Permission was sought from the most senior staff member in attendance before any audio or video recording commenced. The companies were also given the opportunity to review all research outputs before dissemination to ensure accuracy of accounts and that no commercial or personal confidentiality was breached.

This arrangement ensured that the ethnographer had access to the sites to observe work practices, including confidential business processes and systems, although of course ultimately the host organisations decided what access was granted to documentation and what was permitted to be recorded. It also meant that the various approaches taken to the work were chosen and controlled by employees of the company, and care was taken to ensure these were not unduly influenced by the researcher. Host organisations were also given the opportunity to review research outputs before dissemination to ensure accuracy and confidentiality was maintained. Apart from some limited access to company systems and project documentation, very little restriction was placed on the research at either site.

Collected data included field-notes, photographs, documentation, audio and video recordings. The researcher's discretion was used to determine which method of data collection was appropriate for any given situation. This decision was based on practical and political contexts at the time of recording. For example, video was used mostly for recording meetings, audio was used as a back up to video and also for recording interviews. Field-notes and photographs were used within the general working environment. Once collected the data was stored and logged into a corpus index for reference purposes.

3.5.3 Ethnographic approach

This section discusses the methodological approach adopted within the two ethnographic case study chapters (5 and 6). One of the main contributions of this thesis is in the uncovering of 'machineries of interaction' (Sacks, 1984), and presentation of such, as rich descriptions of the situated action involved in IoT design work. This has been achieved through ethnomethodologically informed ethnography (Garfinkel, 1967). This approach to ethnography is common within Human Computer Interaction (HCI) and Computer Supported Cooperative work (CSCW)(Blomberg and Karasti, 2013; Crabtree et al., 2012; Randall et al., 2021), it is an approach particularly well suited to studies of work (Button and Sharrock, 2009). Thus it is deemed appropriate for the two commercial settings that have been studied here, to explicate the work of IoT design 'in the wild'.

The scientific foundation of ethnography, as an approach to studies of how groups of people actually engage in the activities surrounding their lives, has its roots back in the 19th and early 20th centuries. At this time the type of ethnography being conducted by anthropologists was revolutionised by the work of (Malinowski, 1922; Button and Sharrock, 2009), in that they began immersing themselves within foreign cultures. This enabled deeper insights to be gained into the everyday phenomenon of their research subjects, rather than to look upon their practices, while applying their preconceptions, from a distance. Malinowski (1922) demonstrated a new approach and encouraged his peers to fully immerse themselves, in order to find and report from the 'native's point of view'. This approach requires time and dedication alongside a willingness to move beyond the western perspective of looking in, and gain a deep understanding from within. These early iterations of ethnography were applied to understanding the culture within foreign lands and are therefore not directly relevant to the approach taken within this thesis, however, this work is often cited as relevant to the foundations of the type of ethnography practiced within sociology and later to studies of work related to HCI (Button and Sharrock, 2009).

The Chicago School of Sociology have been credited with bringing ethnography home to consider native culture within their own city. Studies were conducted to understand the 'ways of life' within different localities of their own city, in a bid to uncover the 'developing dynamics of the city' (Button and Sharrock, 2009). Robert Ezra Park, Ernest Burgess and colleagues were sociologists working from an 'interactionist' perspective bringing in techniques from Park's journalist background. The foci of their work was that of the perspectives of the inhabitants of the settings they were studying. In the second generation of this work at the Chicago School of Sociology Hughes (1958), focused his approach on occupations and professions encouraging students to study professionals within their city, such as taxi drivers, caretakers and musicians. Mentored by Hughes, Howard S. Becker used ethnography to study the work of Jazz musicians (Becker, 1976). In his detailed descriptions of the work of Jazz musicians, Becker provided insights about the structure and organisation of the work and related interactions, such as, requests from their audience, colleagues and earnings. However, this work was criticised by Sudnow (1993) as omitting the crucially important aspects of explicating what the musicians actually do in the making of the music. Sudnow referred to this as the 'Howard Becker phenomenon'. Garfinkel (1967) builds on this as a criticism of traditional sociological approaches in missing the actual 'work practices' they are claiming or attempting to study. This 'oversight' of traditional sociological studies is referred to as 'the missing what'. It is the focus of Garfinkel's ethnomethodology to uncover this through explicating the member's methods that make up the actual 'doing' of the activities within the setting. That is to unpack the interactional work that is done in the 'doing' (Button, 2000; Crabtree et al., 2009).

3.5.4 Ethnomethodologically informed ethnography

Ethnomethodologically informed ethnography (Garfinkel, 1967), as adopted within this thesis, maintains a focus on observing and explicating the naturally accountable order within a setting to uncover the 'machineries of interaction' (Sacks, 1984). In other words unpacking how members of a setting self-organise to collectively achieve the practical accomplishment of IoT design. It uncovers what members of a setting know as normal, mundane and recognisable in the doing of a particular social action. What is important to an ethnomethodologist is to maintain an indifference (Garfinkel, 2002; Lynch, 1999) from theory about why people may or may not be doing things in a particular way to focus only on the natural or ordinary accountability. That is to say we are concerned with what is ordinarily recognisable as this or that activity by members of a particular setting.

For a researcher undertaking ethnomethodologically informed ethnography to be able to successfully attend to a setting and avoid missing what is 'done in the doing' (Crabtree et al., 2012), they should maintain ethnomethodological indifference. That is to say, in order to achieve 'unique adequacy' and 'vulgar competence' (Garfinkel and Wieder, 1992) so as to understand the naturally accountable order of a setting as its members do, one needs to attend to the members' methods. That is, the methods that allow them to understand the actions of others and to collectively get the work done in a way that is indexical of the situation itself (Garfinkel, 1967). It is worth clarifying here that the term work is used loosely to represent 'activities' of a setting (Crabtree et al., 2012).

Ethnomethodologists believe that members of a setting are practical sociologists that understand and reflexively interact with a situation to undertake and achieve various activities that make up our everyday lives (Crabtree et al., 2012). In this way the members of a setting see and understand what is going on around them, what their actions mean and those of others within their social setting. The natural accountability (Garfinkel, 1967) of this means that members can provide an account of what is happening in a way that is recognisable to others (Button et al., 2015). Classic examples here include queuing (Garfinkel and Livingston, 2003) or mail placement within the home (Crabtree et al., 2012), where members understand what is happening around them as they seamlessly slot into the social order to achieve what they have set out to do.

In summary then, it is the job of an ethnomethodologist to unpack the *members' methods* of a setting, to uncover the *machineries of interaction*, through attending to the sequential and interactional order of things, so as to achieve the *'vulgar competence'* leading to a *'unique adequacy'* to report the *natural accountability* in such a way that is recognisable to the members of that setting as the work being done.

Unpacking this naturally accountable work in a setting, is important for the informing of the design of systems to support or fit in around these activities. Button and Sharrock describe this succinctly:

> "If we are to place computer systems in the workplace, then understanding the ways of that workplace is an important resource in the design process. "(Button and Sharrock, 2009, p.10)

While the aim of the research in this thesis is not necessarily to inform the design of a computer systems, the same approach can be applied to work processes, methodologies and frameworks that are being designed to fit into a 'workplace' to support the members within it. For example, a design framework, methodology or tool to assist practitioners with challenges in the design process of IoT products.

3.5.5 Analysing the data

Shortly following data collection, the data corpus was indexed and catalogued on a spreadsheet, hand written field-notes were typed up, saved and catalogued along with video, audio and documentary data. Brief descriptions of the content of each item was included in the cataloguing process. Due to the size of the corpus, filtering was applied to concentrate on a particular project or focus area. For example, a 3 hour trouble shooting and design meeting for study II and a two week sprint for study III. This involved multiple reviews and cataloguing of the whole corpus, followed by the selection of episodes from the recorded data, which demonstrated challenges, tensions, design reasoning and decision making of the team.

The selected episodes were then transcribed and further analysed through a process of horizontal and vertical slicing (Crabtree et al., 2012). Transcription was conducted manually, as an exercise of refamiliarisation and immersion into the data. As with the thematic analysis applied to the interview study, grammar and syntax were improved to enhance readability through denaturalisation during transcription (Oliver et al., 2005). Following multiple reviews of episodes of focus were selected (in line with best practice outlined by Heath et al. (2010)), initially described and analysed, then further reviewed collaboratively at data sessions with two or three other researchers from the same research group. Each data session involved thorough analysis and critical reflection of the episodes. During the data session, video clips and transcripts were presented alongside contextual descriptions to situate the episodes. The results of this approach and analysis are presented within the study chapters (5 and 6) as fragments depicting 'vivid exhibits' (Crabtree et al., 2012) as exemplars supporting thick descriptions of the activity and machineries of interaction as they unfolded.

Chapter 4

Study I - Industry overview

4.1 Chapter overview

This chapter presents the first empirical study of this thesis. This is an exploratory study focused on gaining an overview of different types of design work taking place on IoT related projects within commercial settings. In particular, providing insights into design challenges and approaches from a variety of different industry perspectives. The core aim of the study is to provide a foundational understanding of the landscape in which this thesis is situated, in order to provide both platform and direction for the subsequent ethnographic case studies presented in chapters 5 and 6.

The industry overview presented consists of knowledge gained through attendance at industry events and practitioner accounts in the form of presented talks and semi-structured interviews. An account is presented first describing the format, structure and content of industry events attended as part of this research. This is followed by the findings of 11 mini case studies in the form of semi-structured interviews with practitioners directly involved in or overseeing design work on commercial IoT related projects.

4.2 Introduction

The intention of the research presented in this chapter was to gain an overview understanding of ways in which practitioners organise their work when designing within this field, and the challenges they face in completing the work within their practice contexts. As demonstrated with chapter 2 of this thesis a research gap exists with very little research investigating the IoT design (Lee et al., 2022). The IoT presents a distinctive design space due to the multifaceted nature of connected products. This creates unique challenges for designers as they negotiate their way around the different technological layers (Lee et al., 2018). Thus there is little knowledge about the challenges and social organisation of the work of design within this industry. Particularly understanding *how* the unique design challenges within this space are addressed by practitioners. As demonstrated in section 2.1.2, Ubicomp research has highlighted some practical challenges but as yet these have not really been explored in practice environments.

The Internet of Things is a growing industry spanning many different markets and sectors with worldwide device forecasts going from 9.7 billion in 2020 to over 29 billion in 2030 (Vailshery, 2022). As the industry matures it is becoming much easier for businesses and individuals to create IoT products and to release them onto the market. Components and resources are more readily available and a range of supporting services have been developed. Connected devices can now be seen in virtually every business sector. The breadth and depth of this industry mean that research must focus in on specific areas in order to produce detailed insights about design practice. This chapter therefore provides an overview as an initiating step in focusing the research contained within this thesis. In addition to this, the study also served to increase researcher knowledge so as to work towards the ethnomethodological requirement of 'unique adequacy' (Garfinkel and Wieder, 1992) as outlined in the methodology chapter (section 3.5.4)

The findings of this study present a broad overview of the IoT industry through focusing on industry events and practitioner accounts. The interview findings in particular, provide insights into some core challenges faced by IoT design practitioners through a thematic report. These are categorised as challenges around embeddedness and the long-term nature of IoT solutions, as well as business related constraints.

4.3 Industry events

As part of this exploratory study a number of IoT industry events were attended in order to achieve a broad understanding of the ways in which practitioners interact with each other. Table 4.1 provides a list of events and meetups attended during this phase of the research. These can be divided into meetup group events, expos and other events. Fieldnotes were taken at each of these events and documentation, such as programmes, were also collected.

Meetup Groups	**Expos & Events**
Tech Nottingham	IoT Tech Expo (Global)
Women in Tech	Wearable Technology Show
Nott Tuesday	Digital Health Technology Show
Nottingham Artificial Intelligence	Eco Build
BCS Nottingham & Derby	Kitchen & Bathroom Show
IoT London	IoT London Showcase Event
IoT Midlands	Pixel & RPD panel discussions
Hardware Pioneers	Inspire Women in Tech
IoT Nottingham	

Table 4.1: Events attended as part of the industry overview study

4.3.1 Meetup groups

Meetup group events are usually held in the evening within company offices or meeting areas, in hotel conference rooms or innovation centres. They are often quite small affairs ranging from around 10-30 people. The events are free to attend, although for many, places need to be booked in advance to prevent over subscription. For some there is also now an online hybrid model. Initially this was as a result of the Covid19 pandemic, however, some have continued with this approach since restrictions were lifted. The general format of the meetup sessions remains fairly consistent across the different groups and topics. They begin with an informal networking session which is followed by around 2-3 10 minute talks, each followed by 5 minutes of questions. There is also time for food and drinks between talks, which is often paid for by corporate sponsors. Some of the attended meetups also have email newsletters that accompany them which provide a sense of membership that does not appear to be achieved through the one off or annual events and expos.

The topics of the meetups vary considerably some of the ones visited as part of this research were specifically IoT focussed and others were more general but contained some IoT related talks within them. For example, IoT London is a large, focussed meetup that is very popular. Tech Nottingham on the other-hand, whilst still popular, has a much broader focus. In general there were 3 core types of talks, emerging related technologies or regulations and their potential impact on businesses within the industry, accounts of interesting projects that practitioners had been involved in and sales pitches for supporting services (such as, hardware design). There were also occasional talks by academic researchers discussing their projects, although this was a rare occurrence. Some of the larger more IoT focused meetups, such as IoT London and Hardware Pioneers also run annual expos in place of one of the regular meetups. These consist of members showcasing their products and services to other members of the meetup group.

The attendees at the IoT specific meetup events include:

- Small to medium business professionals working on IoT products and services
- People who represent businesses that provide supporting services to small business professionals (for example, catapults, venture capitalists and cloud service providers)
- People who are interested in moving into the field and are looking for connections to assist with a career change
- Individual start-up founders working on their own looking to expand their knowledge or network
- Researchers working in the IoT space, such as myself

As part of the exploratory research within this thesis the meetup events were utilised in various ways. They were attended on multiple occasions in order to gain a detailed understanding of their workings. Research strategies included networking, discussing the research being conducted, conversations with practitioners relating to their experience, current work and practices. Business cards were exchanged with numerous practitioners and social media connections through Twitter and LinkedIn were made.

4.3.2 Expos and events

Expos are free to attend and are either large events held at dedicated exhibition venues or are small more focused affairs held in hotels or offices. A key feature of all of the expos is stalls promoting or demoing commercial products or services. The larger expos often feature conference style tracks designed to attract corporate guests. These conference tracks consist of a handful of free talks, in addition to a number of high profile talks by representatives from large corporates sharing details of specific projects, products or approaches. Registration for the main talks require a fee to gain access. The events, in this case were held in innovation centres and were focused around formally structured panels and talks.

As with the meetups discussed in section 4.3.1 these events were attended for 2 key purposes. Firstly, the aim was to gain an overview of the IoT industry to develop thorough knowledge and understanding of the field from the practitioner perspective. The second goal was to make contact with various practitioners to discuss the research and the potential of participation either in the form of an interview with a relevant person in the business or as an ethnographic fieldwork partner. Again, business cards were exchanged with numerous practitioners and social media connections through Twitter and LinkedIn were made. As these events were more formal than the meetup events the networking was not facilitated through the event structure in the same way. It was therefore more appropriate to initiate the contact by visiting the dedicated stalls and discussing the products and demos on offer.

4.4 Practitioner interviews setup

The second part of this industry overview study is made up from 11 semi-structured interviews with practitioners. The following sections will describe the details of this interview study including the recruitment of participants, the structure of the interviews and the key design challenges identified through a thematic analysis of the interview transcriptions.

4.4.1 Participant recruitment

This section provides an overview of the interview recruitment process including details on the number and types of participants recruited and some of the access challenges faced during this process.

The industry events described above allowed a platform for further networking in order to recruit interview participants. Information about the study was informally discussed with other attendees, speakers and exhibitors at these events, with business cards exchanged and follow up emails sent where initial approaches were positively received. Care was taken to include a wide variety of domains, roles and company types.

In total 11 participants took part in the study, all of whom were over the age of 18. As a prerequisite for taking part in the interview study participants self-reported previously being involved in design elements of an IoT related project. Table 4.2 below provides an overview of the recruited participants, including the sectors of projects discussed, recruitment channels and project types. There was no prerequisite for projects to have reached a particular stage before the interview. For this reason, the projects discussed range from mid development phases to products that had been successfully launched into the market for a period of time. For the core projects discussed in the interviews this equates to 6 products and services that had gone to market and 5 that were still in the development stages. However, while this provides an indication, participants often digressed onto other projects they had been involved in so this is not an exact reflection of all the projects that were discussed.

The IoT industry (as noted in section 2.1) is vast and covers almost, if not all business sectors. It is therefore not practicable to attempt to address all of them within this study. The focus here (as specified in section 2.1) is on personal and enterprise level devices and related services. A broad range of sectors have been touched upon (as demonstrated in table 4.2), however, notable exclusions include, aerospace, automotive, agriculture (Agri-IoT) and industrial IoT (IIoT). This is partly due to the opportunity sampling approach taken and access challenges of recruiting employees from larger businesses for interviews (as discussed in section 3.4). While this can be seen as a limitation of the research, even without these access challenges the depth and breadth of the IoT industry means it is not realistic to attempt to study the full range of challenges and settings in detail. It was therefore necessary to focus the research in specific areas to ensure that findings were focused and that saturation of responses could be achieved within a realistic project time frame.

P	Sector	Project Type	Recruitment
1	Retail	Point of Sale Device	Introduction
2	Energy	Mobile app for emergency response	Introduction
3	Household Pet	Pet monitoring device	Expo/Event
4	Education	Movement logging device	Social connection
5	Multiple: Health, Catering Animal Care	Environment monitoring device	Expo/Event
6	Multiple: Agriculture Shipping	Location tracking technology & device	Meet-up group
7	Multiple: Smart home Adventure	Commissioned product design	Meet-up group
8	Circular Economy Waste management	Monitoring device and Voice interface application	Meet-up group
9	Femtech	Medical grade device	Introduction
10	Multiple: Retail, Transport Distribution	Interfaces for service devices	Meet-up group
11	IoT	Platform to support device producers	Introduction

Table 4.2: Interview participants, recruitment route and project details

4.4.2 The interview process

The interviews were semi-structured and involved participants discussing elements of the product and the design processes they had either overseen or been directly involved in. Prompts were provided to encourage discussion around design practices, resources, challenges and approaches. Interviews lasted on average around 30 minutes but this varied depending on how much the participants wanted to say. For example, two interviews were less than 15 minutes and two lasted for around an hour.

The interviews progressed in such a way as to ensure core topics were covered, but were flexible enough to allow relevant divergence by the participants onto broader IoT related topics. Where participants accounts of a particular topic had come to a natural end or the researcher deemed the topic to have gone too far off track they were prompted through the use of a question relating to one of the following;

- their own role in the design work on the project
- the structure of the design team
- design processes or procedures
- tools and resources used
- design challenges experienced, particularly those in relation specifically to the IoT domain

This approach was also taken where clarification was being sought over something that had been glossed over or only briefly mentioned by participants. For example, *"you mentioned [x] could you tell me a little more about that"*. This allowed flexibility whilst still addressing the research questions of understanding the organisation of work at a general level and more specifically in relation to approaches to design and challenges faced during the process.

When the conversation digressed into more detailed or technical aspects of products, other IoT related projects they had worked on, or more broad discussion of the IoT, no intervention was made by the researcher, thus allowing unstructured exploratory elements to creep in. Where there were pauses, breaks or digression from the topic, intervention from the researcher was used to introduce another question. When all question areas had been covered within the interview the participants were asked if there was anything else they would like to add.

4.5 Interview findings

The findings of the study demonstrate a number of challenges and related approaches to design work which influence the organisation of the work itself. As shown in table 4.3, these have been grouped into three core themes: The embedding of products and services, Long-term nature of IoT and Business related constraints. For each of these core themes, sub-themes are identified and described below with example extracts from the raw data presented in support of text descriptions.

Embeddedness section: 4.5.1	**Long-term nature** section: 4.5.2	**Business related** section: 4.5.3
Physical environments	Power	Occasioning of the project
Sociotechnical infrastructures	Supply chain risks	Company background
User experience considerations	Modification	Roles and resources

Table 4.3: Themes and sub-themes from interview analysis

4.5.1 The embedding of IoT products and service

Due to the combined physical and digital nature of IoT products, challenges around embeddedness are a common feature. Within the interview findings these challenges inevitably came up in a number of different forms. These have been categorised below as relating to; the impact of physical environments, Sociotechnical infrastructural implications and embedding as a user experience consideration.

4.5.1.1 Physical environments

Many of the interview participants described facing challenges relating to the physical environments in which devices were embedded. For some this was directly related to the design of the device itself and for others it related to the design of software or APIs to provide contingencies for physical location based challenges. These challenges have been categorised below as anticipating complexities of harsh environments and fitting things into the physical context.

One of the challenges discussed in relation to embedding devices into physical locations was that of **dealing with harsh environments**. This presented some design challenges for the interview participants, including the need to design software that can cater for unpredictable conditions. A good example of this can be seen in Participant 10's comment below. The location of the devices that he was developing software for raised challenges for both the potential quality of the data being collected and also the reliability of the connection used to send the data.

> *"these things are mounted on either bridges or poles at side of the road"* - (P10)

In this case weather, dirt deposits and remote locations were all potential disruptions that needed contingencies to be designed for. The approach taken to these issues was to include confidence levels and reference images in the data sent through to the user and to assess the connection speed when sending data packets so resolution and content adjustments could be made automatically.

Participant 8 also raised challenges relating to harsh environments. In their case the product was designed to retro fit into industrial waste containers. For this product the anticipated problems were in relation to device damage caused by bin emptying activities rather than data reliability in everyday use.

> *"it has to go into that bin, and when the truck comes, lifts up the bin, dumps it and bangs it down again, that vibration, I can't have my boards just crumble, so it's a proper engineering challenge"* - (P8)

At the point of interview the product was still in its development phase and this challenge had not yet been resolved. While one approach to this may be to focus on the encasing of the device, this in itself can raise further complications in relation to accuracy of data readings, as noted by Participant 5.

> *"one of the challenges for us is getting a, accurate reading when it is, when our electronics are enclosed in plastic, that's quite a challenge"* - (P5)

For all of these products, and arguably most IoT products, accuracy and reliability of data is key to the service they provide. Therefore ensuring the provision of that from their installed location, regardless of changes in the physical environment in which they are embedded, is essential. For this reason it is important for the designers to consider possible consequences of harsh environments when designing the hardware, software and data processing protocols.

In some cases it is essential that devices fit into the physical context in a way that is both **practical and aesthetically pleasing**. This is particularly true in the case of wearables, where the device is designed to be worn by a person or animal. For example, Participant 3 notes size as a key challenge in the design of their pet monitoring device.

> *"There's also actually technical challenges so making it small, which is difficult"* - (P3)

In this particular case, the device needed to be functional and reliable but also small enough to not be disruptive to the animal wearing it. While electronic components continue to get smaller achieving the required power levels, processing and sensors within such a small device is a challenging balancing act.

In addition to this practical approach of ensuring the size of the device is fit for use in the intended context, some interview participants also raised look and feel of devices as important. For example, the device discussed by Participant 4 was designed to 'just sit on a wall' and therefore didn't have the same level of size constraints as the wearable described by Participant 3. However, the aesthetics of Participant 4's device was still a consideration for them, in terms of how good it looked within that context.

> *"we just wanted a device that would be, that would just sit on a wall and just look not too bad, look quite good, but just sit on a wall"* - (P4)

Interestingly **designing for out of context use** also came up as a challenge within this category. This was particularly prominent with regard to the ability to demo the product to potential customers and for guiding design work through live demos for users or for in-house testing. Often this **'demoability'** needed to be somewhat out of context for where the device would ultimately be used. Participant 4 sums this up nicely demonstrating how the business requirement of allowing customers flexibility when trialing devices led to the design decision of including WiFi functionality.

> *"when a customer's like piloting something you really need it to be able to go anywhere you just need it to be able to you know just sit it on a desk or just plug it into some power somewhere, and that's why it needs to be WiFi connected."* - (P4)

Participants 3 and 9 also noted designing for out of context use.

> *"we made integrated demos, so we've, made the hardware to kind of demonstrate some of the features"* - (P3)

> *"we built a research app separate to the production app... we actually built that first and it allowed us to actually kind of test certain features that we were thinking about and actually pull data off the hardware."* - (P9)

For their purposes, however, it was related to prototype demonstration rather than the sales related demonstrations of the finished product and therefore was less related to embedding the device into a physical context and more about a prototype fitting into the context of their design process and providing visibility of data and functionality to support design reasoning.

4.5.1.2 Sociotechnical infrastructures

When considering embedding an IoT product into an environment it often goes beyond just the physical location. In many cases there is a sociotechnical infrastructure associated with its use that needs to be considered. For example, there may be IT systems and processes already in place that need to be incorporated. There may also be routines or work practices that the device or service is being designed to support or augment. It is important to consider not just the individual elements themselves but also the potentially complex relations between the various infrastructural elements. Within this section the challenges discussed by interview participants in relation to embedding into sociotechnical infrastructures have been organised into sections about users, customers and clients, as well as regulation and certification.

Users, customers and clients

Within this theme, complexity is seen in the relationships between users, customers and clients. This can be particularly complex where multiple businesses are involved in the use of the product. Participant 11 provides a nice example of where they have considered how multiple users and consumers may use their platform.

> *"the people who make the devices are also consumers of our platform, and, I'm not sure if I would say that this is a new thing for IoT, I mean, the relationship of for example [a coffee shop] with their hardware vendors predates IoT by a long time. So one of the things that we've had to deal with as we launched this product... is the complexity in the ecosystem that connects in the supply chain. Which is just, you know, it's huge, it's a very very complex beast."* - (P11)

The platform itself is a supporting service designed to help businesses working in IoT to manage and monitor their devices in various ways. Finding ways to understand the complexities of these relationships between users is an important consideration in the design process. These challenges are not only limited to external relationships between users, they can also relate to how devices are embedded into established physical infrastructures and the relationships that these already have with their users. For example, Participant 4 describes a problem relating to the way a customer's WiFi network is set up for people rather than devices.

> *"when it comes to an actual device a lot of places are not necessarily geared up for devices to be connecting to their WiFi network they're really set up with a view that people are"* - (P4)

In this specific example there are security protocols on the network which runs weekly password changes, this presents technical design challenges that need to be considered.

> *"See we've got like one customer that the WiFi network they want to connect to, the password changes every week, which is like, you know, it's a pain. We really took the view that you're gonna configure it, put it on a wall and leave it there for 2 years, pretty much, but certainly not, the whole idea of changing a password every week doesn't work at all, just doesn't work at all"* - (P4)

While this is a technical challenge that could be dealt with on an individual level, as a product which is being distributed to multiple customers across multiple countries, it is not usually commercially viable to tailor it to each customer's requirements. Design decisions of this sort therefore need to consider the customer base as a whole as they carefully balance compatibility with a users infrastructure and with the commercial viability of the product. As an agency providing IoT based beacons to be embedded within retail businesses Participant 1 also raised some interesting challenges in this area.

> *"We're not for instance allowed to put beacons into [a particular client's sites] because they've just said that they're not compliant with their current IT setup etc. they're not happy with them going in, and actually what it really says is that the IT Director doesn't believe in them as a tool so he's come up with all sorts of excuses and reasons why they can't be put in the [sites]."* - (P1)

In this case the challenges stem from an internal sociotechnical infrastructure where authorisation is reliant on compliance with their technical rules, regulations and set up, with a particular person acting as a gatekeeper. He also noted similar problems as more general to their customer base in relation to physical retail spaces.

> *"there's all sorts of IT rules about what you can and can't put on a store network etc. so you're quite restricted sometimes in what you can do and it takes a long time to get stuff away."* - (P1)

Regulation and certification

When dealing with physical products, particularly in some sectors such as products for children or health care related products there are essential regulations and certifications that need to be adhered to. This is no different for IoT devices and is something that was raised as a challenge by some of the interview participants. Without these certifications it would not be possible to get these products into their intended market to reach their consumers. Participants 5 and 6 describe their challenges of meeting the relevant safety regulations as time consuming and costly but an essential part of the design process.

> *"we've had to modify our design according to, child safety specifications, there are a lot of child safety specifications that you have to adhere to here in the UK, Europe, the US and Canada. .... the design had to be modified more than 10 times to meet the safety requirements, but also to make sure that, we were happy that our product was going to be the safest product that it could be"* - (P5)

For Participant 5 it was important for them to ensure that their baby product achieved these safety standards to ensure that parents were confident about its use. However, they also note it was also useful in giving them the confidence that their product was as safe as possible. For Participant 6 even though the product was still in the development stages and had not yet been through the certification process, it was an important consideration for them throughout the design work.

> *"fortunately we are using standard components that have already been certified for, that already have RH certification CE and FCC approval and so on, but when we put them all together on our board we'll have to submit them for CE and FCC approval oh and radio-frequency certification, and, the environmental, to certify that it can achieve IP 67 and so on, that'll be very costly, time consuming and, well time consuming and expensive."* - (P6)

Participant 9 also had to navigate a medical device approval process. This was a new process for them so they took the approach of hiring a consultant to ensure the project remained on schedule.

> *"its an FDA class 3 medical device... we had to go through an FDA approval process... our head of ops worked on it with a*

> *consultant because none of us have done that before and equally that put the timelines at risk"* - (P9)

The above challenges relate to physical devices within specific market places which is not necessarily unique to IoT. However, certification challenges were not only limited to businesses building and releasing physical devices. They can also present design challenges for projects that utilise other devices or platforms. Participant 8 discussed certification challenges in relation to a skill they had launched on Amazon Echo.

> *"at the moment it's quite a conundrum because it's saying that we've failed certification because, when the tester, the developer who was testing it answered a question, it was a yes no question, and he's saying that when he said yes, that Amazon, that the Echo box errored out"* - (P8)

This proved to be especially challenging for Participant 8 as they were unable to replicate the error in their own testing. This resulted in the product release being unable to move forward as they had been unsuccessful in meeting the platform requirements. In cases such as this where part of the product delivery infrastructure is not under the direct control of the business developing the product the challenges and risks related to certification can be critical. It is worth also noting here that for the business providing the platform as a delivery mechanism (in this case Amazon) they are also facing challenges in relation to the provision of consistent quality for their users. For this reason, this type of self-governed certification is common for businesses deploying secondary services onto IoT devices.

4.5.1.3 Embedding as a user experience consideration

There are a number of considerations and design approaches that came up in the interview data in relation to embedding and the design of the user experience. One of the key challenges in this area is achieving a consistent experience for the user across different product and service layers, i.e., ensuring product layers are seamlessly embedded within the overall experience. A further consideration is the physical installation of the product itself.

Creating a cohesive product experience

As Participant 7 notes below, IoT devices are part of a wider system that is ideally designed to work cohesively together as one user experience. This can be a complex challenge for designers due to the number of different elements which make up the product and service as a whole.

> *"when it was a toaster, it was literally that thing, you were dealing with an engineering package and you had to manage, manufacturing, aesthetics, desirability and all of those kind of things, but with IoT it means that the product is part of a wider system so when you conceive of the design, you don't start with the product, you design the experience and that helps you design what it is. So that makes it a bit more distributed so harder to pin down."* - (P7)

Participant 9 also noted the desire to create one cohesive user experience across the different layers of the product. Their approach to this challenge was to attempt to use a shared design language to ensure all the relevant teams across the business were working together to create this.

> *"what I want is the user to have one seamless experience, one cohesive product experience and so just trying to pull those teams together and make sure that our design language is shared as much as possible for the whole product experience from unboxing it through to customer care is actually feels like it's, one product and from one brand"* - (P9)

In a number of cases there were communication challenges between the physical product and software teams. These arise from the different backgrounds of the two design teams. For example, engineers are focused on ensuring the product is right before launch as it is hard to make changes after this point, whereas for software developers, the focus is to launch and then continue to make changes. This resonates with comments from Lee et al. (2018). Participant 7 describes this from his experience.

> *"product [design] particularly is still at a point where what we're aiming for is perfection, because we have to cut steel, spend a lot of money and then we'll amortise the cost over so long. Whereas sort of product experience, because it involves software is more about well just getting things working, and actually trying to learn in the experience."* - (P7)

This disconnect between the motivations and work streams of the hardware and software teams highlights the challenges in embedding the different layers or elements of the product together to create one experience for the customer. This challenge is prominent for companies who are creating the device and software elements and for those who are attempting to work on just one layer and integrate it with other product or service layers being developed elsewhere. For example, as discussed above in relation to designing a skill for Amazon Echo. It is important for both parties involved to ensure that the service as a whole offers a consistent user experience. This applies to echo users who come across the skill and for direct customers of the service provided by Participant 8. Participant 5 notes the importance of the device and app having the same level of design to give consistency.

> *"how does the design match up, it's interesting about app design because our initial apps were very, we were like we have to make them look beautiful and have that high level of, design that the products have, whereas actually what's important, and I'm not*

> *saying our apps don't do that now but earlier we would put more emphasis on, making it pretty, but now our focus is on the functionality and the use of them"* - (P5)

It is also worth noting here that once their initial look and feel had been put in place to achieve the aesthetic consistency the focus of the app design moved to usability and functionality. This included the implementation of some on-boarding instructions to help users with configuring various settings during first use. This demonstrates how they used the aesthetics of the physical device as the anchor on which to 'match-up' the design of the app. However, once that initial aim had been achieved it was still possible for the software developers to learn and update the functionality without losing that connection between the two elements.

Installation and configuration

Installation and configuration is not something that came up often within the interview data. It is therefore being drawn out here as something which may need further investigation in future studies. Where it did come up in the interviews it related mainly to providing instruction guides and tools for users to self install. For example:

> *"we've got a document which is like a quick start guide for a customer, it's like a 3 page document, for the customer to know how to configure those devices"* - (P4)

> *"we have instructions inside our apps now which we never used to do so, a little popup will come up and say, how to-, you know, give them instructions about how to change the date format you want, so it's really easy for people to use"* - (P5)

In summary, the embedding of IoT products and services is complex with challenges spanning beyond the physical environment and into the social structures and user experience expectations. Of course, the initial embedding and set-up of the device and app is just one small part of the product experience. As many IoT products have heavy ongoing service elements, the longer-term usage of IoT must also be considered here. Which brings us onto the next theme.

4.5.2 Long-term nature and ongoing service elements

While not discussed directly as part of the design process, many of the challenges that came through in the interviews were related to the long-term nature of IoT products. These challenges were more prominent within businesses who were creating their own devices rather than those who were working closely with third parties either as agencies being commissioned to do design and development work or those creating services to run on other devices (such as, Amazon Echo or mobile phones). Unsurprisingly the most common of these long-term challenges was relating to power supplies for devices.

4.5.2.1 Power

Power was reported as an influencing factor in design decisions in two key ways. Firstly this related to the provision of power to the device including consideration of different options and secondly it related to minimising power usage. Some of the decisions about the power source were driven by specific needs of the user or client that had been discovered through an element of user research related to the project. For example, Participant 1 explains how their clients were not happy with undertaking battery replacement and therefore preferred a mains powered option to be employed.

> *"I wanted it so that it wasn't reliant on batteries because lots of people were saying well we don't want battery powered objects*

> *in our stores because we'll have to replace it in a years time."* - (P1)

Participant 4 also wanted to incorporate a mains powered option, however, they chose to go with power over Ethernet because that was the most convenient option for their circumstances and the placement of their devices.

> *"we also wanted to have power over Ethernet in there, so he incorporated that at the same time. So that was something on the, on the design side that I had done. I had done nothing to do with power over Ethernet, but the board he designed did have that"* - (P4)

In many cases, for example, portable or wearable devices, mains power is not a practical option, which presents further challenges for design teams. With some devices such as the pet wearable discussed by Participant 3 and the femtech device discussed by Participant 9 an on-board battery with charging facilities is the obvious option as the devices are interacted with regularly or are easily accessible to users. However, for some other types of devices this is not as straight forward. For example, Participant 8 discusses the difficulty of accessing power for their industrial bin based device:

> *"so the power issue, obviously a bin is standing in a [supermarket] parking lot, there's no power, there's no place where you can just plug it in, so, and a lot of IoT guys have this problem"* - (p8)

This was also a problem for the GPS tracking and monitoring device discussed by Participant 6.

> *"power is not that much of an enabler it's a constraint... I started to work on, on the kind of technology that would be appropriate for, regenerating power in a small device"* - (P6)

The second theme that came up in relation to power was that of reducing the power consumption of devices. This was something that only came up for devices that were not mains powered, and that either were hard to access or required users to charge them. Participant 6 describes the challenges between these two key aspects of design relating to device power as something which requires careful consideration.

> *"we're walking a tightrope between the power we can, harvest and so on, and power we have to use, it's very very very careful attention to detail, and tweaking"* - (P6)

The design challenge of minimising power use was approached from a number of different angles. For example, for Participant 6 it was important to ensure their device was commercially attractive.

> *"The other half was minimising the power we have to use in order to provide a commercially attractive service, so we did, and that took a lot"* - (P6)

Participant 3 also focused on making their product commercially attractive to their users:

> *"they also want it to last for ages they don't want to charge things anymore, they've already got a phone that they need to charge once a day so making things last a long time is difficult as well."* - (P3)

In this case it was about the reduction of a charging requirement for their users as this is something their user research had highlighted as important. Participant 8 went into a little more detail about their approach to making design decisions in this area.

> *"a lot of the power is used by sending the data, just by speaking and connecting, so there's something called LPWAN, which is low power wide area networks, cause WiFi, I mean if you have your phone on WiFi within 6 hours it'll probably be dead"* - (p8)

In this case the key challenge was about assessing what was using the most power within their particular device and looking for connectivity supplier options that would best support their requirements to minimise power use to ensure longevity in their service with minimal maintenance requirements. This demonstrates the ways in which power challenges are influenced to the hardware, software and infrastructure choices made within the design process.

4.5.2.2 Supply chain risks

When producing devices one of the key aspects of design work is that of designing for manufacture or assembly of the finished products. This process involves careful planning to ensure that devices are made efficiently and cost effectively. Participant 3 was in the process of designing for manufacture when the interview took place:

> *"We're now working towards design for manufacture, so making sure that we can source all parts, in volume for a low price, or lowish price"* - (P3)

The comment from Participant 3 states "low or lowish price" indicating an element of balancing cost with quality and design. These costs are based on current supply costs which have the potential to fluctuate in future, therefore it is also important that they consider the volume carefully.

For Participant 5 the focus was more on the cost of assembly of the device rather than the cost of parts.

> *"it's really important when your producing a product on mass, you know on a mass scale in bulk, that you've got something that is relatively easy to put together"* – (P5)

These costs of manufacturing and assembly can be difficult for designers to predict and manage as they may not have all of the available information at the start of the design process. This is especially prominent where businesses are moving into the field of IoT and may not have prior experience of the manufacturing process. This is expressed by Participant 5 as she discusses lessons learned from the first product that they launched:

> *"subsequently we've learnt quite a lot through doing that process because [our first product] is quite a time-consuming product to assemble, which, you know in the beginning you don't know that"* - (P5)

Many of these costs are dependent on external suppliers and are therefore not necessarily controllable or predictable in the long-term. There are risks attached in relation to suppliers making changes to either their products or processes that could impact the long-term offering of the IoT product or service. Participant 4 notes these risks and highlights the added complications it raises for smaller businesses where ordering large quantities in one go is not an option.

> *"if you're kind of in a start-up situation, you can't do massive quantities. You can't order a thousand, you've gotta be doing like small quantities, you've got to get it from suppliers that can help you. But whether you'll be able to rely on them over time*

> *to give you that exact same thing at the same price, who knows"* - (P4)

For Participant 4 this challenge led to the requirement of using smaller companies which, in his opinion may be less reliable in terms of consistency for future orders. He also described a difficulty they encountered when an external company in the supply chain did make unexpected changes to their product offering.

> *"when we first got them, the case would come in a nice little box, a little cardboard box, which was great, and then after a couple of hundred they suddenly were no longer able to supply the boxes anymore, so they were just shipping the case. Which is kind of fine, but then we had to think hang on a minute, if we send this to a customer is it gonna be in a box or is it gonna be in bubble wrap?"* - (P4)

This change is fairly minor on the surface as the product being supplied was still the same, as was the cost. However, a change to the way it was being shipped led to changes for Participant 4's business, in that they now needed to consider how to repackage the devices to send out to their customers. These ongoing risks of suppliers making changes are not only limited to businesses who are making the devices themselves, they are also relevant to businesses who are utilising external devices as a delivery platform for their service.

Companies that are utilising IoT are often focused on the 'User Interface' level. In these cases, the interface may need to be designed differently to meet the requirements and limitations of the host devices. For example, Participant 8 discusses launching a product for both Amazon Echo and Google Home. The requirements in terms of the customer experience are the same, however, the devices she is utilising have different ways of working. This has impacted the design work as a different approach is required for each device.

> *"Google is different. Google is using API.AI. . . . . it uses vectors. So [the] word cat is sort of vectorised, it sort of understands ok cat, they're probably talking about maybe their pet food or vacation or all these things. Amazon is not like that at all, if you said cat, it's like okay what was the question again and then it crashes"* - (P8)

Similar challenges are encountered in traditional mobile app design in terms of there being different design requirements to meet platform standards between Android and Apple. At this end of the supply chain, risks exist in relation to platform providers making changes and updates to their systems that in turn require the Service (i.e. App, Alexa Skill etc.) to be updated in line with their new standards. This presents ongoing challenges for businesses deploying IoT related services through or drawing on data from devices which are owned and managed by third parties, presenting an additional need for long-term monitoring, management and modification.

4.5.2.3 Modification

When talking about modification within IoT products and services it is important to consider the different approaches of hardware and software engineers. As mentioned earlier in section 4.5.1 'Embedding as a user experience consideration', there are marked differences between hardware and software in their approaches to design work. These different ways of working can present a number of challenges within design teams particularly in relation to modification after launch. Participant 9 sums these differing approaches up nicely:

> *"I think there's an interesting challenge and one that I felt be-*

> *cause it was an IoT product. That you're working with hardware and software and how those teams work is quite different. The hardware team is trying to build one perfect product or one product that is going to be future proof and still be able to sit on a shelf in five years time, and then you're working with the app team who were just trying to build and ship and every thing and then you know we can continue to iterate. But what I want is the user to have one seamless experience, one cohesive product experience"* - (P9)

This view of hardware as having a level of permanence in relation to its design increases the importance of getting it right before launch, rather than seeing design changes and modification as a long-term option. Participant 4 also commented on the difficulties of modifying hardware and firmware once it's out in the market.

> *"with electronic stuff... once you've got the firmware on your device and it's out in the market, it's very hard to change that, so there's some, kind of risk around the fact that, once you do a release it's out there and there's actually quite a high cost if there happens to be a bug in there, there can be quite a high cost to fixing it."* - (P4)

One approach to this challenge is to release an entirely new version of a product with enhanced functionality. This is the approach taken by Participant 5.

> *"it's quite exciting because last week we actually just released a new version of that product that is really, a really cool product now it does temperature humidity barometric pressure and dew point and it holds 4000 data points of each of those variations*

> *and has much longer battery life and much enhanced IoS and Android apps."* - (p5)

With this approach they effectively replaced the product for all new customers but continued to also support the original version, rather than making changes to devices that were already out 'in the wild'. For many hardware based products, particularly those that connect locally (for example via Bluetooth) and do not have an internet (or cloud) connected software element, modification of deployed products is often not an option except in the most extreme circumstances (such as product recall). It is notable that questions are left open here in relation to obsolescence of older versions of devices and how that is managed from a product or customer support perspective. This was an area that was not raised by any of the practitioners in relation to their products. It is therefore out of scope for this thesis, however, it is potentially an interesting area to explore further in future research.

With some types of IoT connected devices however, a certain level of modification can be achieved remotely. This is something which Participant 11 brought up as a unique opportunity afforded by having a connection in place.

> *"typically pressing buttons on your device it would always respond the same way but if it was cloud connected that it might start responding differently based on, you know, cloud source data...if you are the UX designer you probably used to be in this situation so let's change my UI, I've got new firmware update, maybe that phone update is for the new devices, I'm not going to update the old devices at all right like, all the existing ones have that now, now you know for the next ones our factory roll off have the opportunity to do something new."* - (P11)

In this statement Participant 11 describes a fine level of control over the modification process of IoT products and services. This flexibility is somewhat unique to IoT settings and therefore presents some interesting challenges and opportunities to explore. Questions are raised about the benefits and circumstances of modifying the user experience of a product. For example when is this appropriate and what are the benefits to the business or the user of making the change?

Within the software industry it is common to conduct live research in this manner by deploying different versions to different user groups (i.e. A/B testing etc.) (King et al., 2017). These approaches are more limited when it comes to changing the physical hardware, however, as Participant 11 points out, the responses to specific interactions could potentially be changed. This is unique to IoT as with hardware only product design this testing is traditionally done before launch.

Participant 7 is from a product design background. They describe the difference between designing a static product that can easily be tested and verified before launch to designing experiences which are much more complicated and difficult to fully verify as a prototype.

> *"So if I just did a toaster we'd all look at it in the studio and go yeah we like that one does the client like it, and then you might put it out to some panel testing... get people's opinions. But these days, if you've designed an experience you can't just show them an object and ask them to comment on it, what do you like about it, what does it say about it, you have to, almost prototype it first of all so you can, live the experience and know how it feels, and then actually, how do you prototype things in the wild so you can learn from lots of people"* - (P7)

In these cases it is not only important to ensure that usage data can be reviewed and analysed. It is also important to ensure an element of modification is possible after launch so any learning from testing IoT solutions 'in the wild' can be actioned as changes to the product and/or service.

The ability to remotely review usage data of different users in this way, also makes service based business models (Rejeb et al., 2022) become a more viable option for businesses deploying products into this space. This model traditionally works well from a business to business perspective. For example, photocopiers and coffee machines have been known to work in this way prior to IoT. However, as Participant 11 highlights this model is now becoming more manageable and attractive for businesses as they are better able to monitor usage.

> *"you're seeing this business model transformation where instead of saying oh you know I'll sell you this hardware you need to estimate how many you need and your now moving to, we're seeing it move over to look I will provide you with orange chopping as a service and this is how the price scales based on how many. And I'll keep owning the hardware right, I'm leasing it to you and if it goes wrong it's my problem to come and fix it and we have some SLAs and up times and so on, and that then aligns the incentives much better right. it is now for the orange chopping provider, in their interest to make it last as long as possible to service it at the appropriate interval not too frequently not too infrequently"* - (P11)

This ability to view usage data of physical products allows businesses to better tailor their services to meet customer demands. This presents opportunities in relation to longevity of devices, end-of-life responsibility and efficiency of service in terms of device deployment and servicing. Participant 10 also noted the use of this type of information to help improve the placement of smart lockers.

> *"it's intended to send back the usage data for the lockers back to the customer's main office, so they can see which locker units*

> *are being utilised well, which ones aren't, how often they're being used, what time of day is popular and they then can use that information to determine whether they need more locker units, less lockers put in a different place, all this sort of stuff."* - (P10)

The connectedness of IoT products provides these opportunities for access to the up-to-date usage data of physical products. This type of analysis and adaption work has been occurring in the connected software industry for many years with UX designers and developers basing modification decisions on observed user behaviour (King et al., 2017). The IoT has now brought this ability to the modification and management of physical products, opening up new business models and opportunities for streamlining commercial viability.

Another common approach to modification with software based products is to take a more iterative approach and regularly modify or update a product with new versions. However, where IoT is concerned this is also not necessarily as straight forward as with software alone and additional overheads can be seen. For example, software based products that are being deployed on IoT devices, such as, in the case of an Alexa skill, any modification needs to be re-certified before it can be released. As noted earlier, this was a particular barrier for Participant 8 as they attempted to fix some bugs in the code from their first release:

> *"from our first launch we've discovered quite a few bugs so we're sort of stuck in limbo on the second update, because each time you make any changes you have to go through certification again"* - (P8)

This re-certification or approval of updates is fairly common where external platforms are being used for deployment. Mobile and other device based platforms, such as, Amazon, Google and Apple take this approach to ensure quality and consistency in the user experience that they are providing through these hardware platforms. This raises questions about whether these modification overheads are in relation to working with an external platform or because they are needing to tie the changes into a deployed hardware element that needs to remain consistent.

4.5.3 Business related constraints

There are a number of areas in which business constraints influence the design approach and the product or service being developed. These constraints include, the occasioning of the project, company background and the various roles and resources available within or to the core design team.

4.5.3.1 The occasioning of the project

Throughout the interview data there are a number of different ways in which Participants describe how the initial ideas or project scopes were developed. These different approaches included the expansion of a current product, replacing a current product or service to make it more reliable, the IoT movement and focusing on a market before honing down to an activity level.

Expanding a current product

For Participant 4 the project came about as they were trying to improve the data collection for the customers of their current software service. Adding a physical device to aid data collection would allow a level of automation for their customers, thereby increasing the value of the people monitoring service Participant 4 is offering.

> *"so we went hunting for a device that we could recommend to our customers and couldn't find one, and after a few searches*

> *and just not finding a device that we were happy to be recommending to customers, then I just took the view that we pretty much had no choice but to create our own device"* - (P4)

The lack of available product on the market that could be recommended to their customers as an add-on, meant that the company opted to create a device themselves which they could then supply as part of their service. In this case the project was focused on expanding the service and therefore the design focus applied to the project was on expanding the software service by including a physical product to best to meet the needs of current customers. From this perspective the requirements for the new device needed to fit within the current product infrastructure as a core priority.

Replacing a current solution with a more reliable option
Participants 2 and 6 faced a similar problem to participant 4 in that the current solutions on the market were not reliable enough for their purposes. However, in these cases they were not focused on expanding a current product but were looking to replace a current solution with a more reliable option.

For Participant 2 the reliability issues were with the connection of pager devices that were being used for emergency response purposes. This unreliability led to a complete replacement of the current system, opting for a smart phone app rather than a pager network.

> *"the problem is that the pager network is very unreliable so when they do pager tests, which they do weekly, the pagers can have up to like 20-50% failure rate, with the pagers not going off or not being responded to"* - (P2)

This approach to completely replacing the current system meant they could reevaluate the way it works and to add in additional functionality to improve user experience and record keeping at the same time as improving the reliability. The design approach in this case was to review the current system, identify potential enhancements and then start from scratch to build a new alternative.

For Participant 6 it was a more generalised problem around providing power to a tracker beyond its limited battery life. In this case the reliability issues were in relation to providing long-term power to a device that might not be accessible to charge and would not be an option for mains power.

> *"I thought if there was only some way. If she had a tracker, then she would be easier to find, but then I thought, well within a couple of weeks the battery would run out and it would be useless."* - (P6)

In this case the design lens was firmly focused on the power challenges of IoT devices. Once an acceptable solution could be found to this reliability issue the different types of markets that it could be deployed to would be reviewed in relation to where that kind of technology could add value and therefore be commercially viable. While this is a very techno-centric approach in many ways it was initially driven from a real use case identified 'in the wild', therefore an element of focus remained on this particular pain point before being re-applied to wider settings with more commercial viability.

The IoT movement

For some of the interview Participants the occasioning was more about looking for opportunities within the emerging IoT industry. This is particularly true of Participant 5, who were looking to create a start-up and could see that the IoT industry was presenting opportunities for a variety of different devices to be developed.

> *"we completely saw [the IoT] space was going to take off and so just decided that we would set up [the business] and develop*

> *some devices."* - (p5)

In this case the design lens was on finding gaps in an emerging marketplace and adding value to non-connected devices through a connection to aid data collection, visibility and analysis. In a somewhat similar vein Participant 7 notes a focus on marketing a product as a reason to design in connectivity.

> *"It's almost from a marketing point of view, right we're gonna do a new product so lets look at a kettle. Cool we need a connected kettle and you come up with a reason why it should be connected, and it might not necessarily need to be connected you know, but that's OK"* - (P7)

From this perspective the design focus is on how the product is marketed rather than how it is used. While these two things do, or at least should, tie closely together, the design focus in this case is on finding ways in which this proposed connectivity could be seen to add value for users rather than assessing whether or not users would benefit from the connection in the first place.

Focus on a specific market and honing down to an activity level. The final approach identified was companies that select a market or sector to work in. From here the businesses hone down into an area where a connected product could improve an activity or process. For Participant 8 this was an eco-centric approach looking at the circular economy broadly and then focusing on a niche area of that in which current processes could be improved or changed.

> *"we operate in, on a broad sense, in the circular economy, sustainability, but we're sort of championing a niche sector of waste technology"* - (P8)

For Participant 9 this meant focusing on the femtech market where they already had an established customer base and looking for opportunities to develop a new product around that. This approach was very user-centric and involved user testing and engagement throughout the process.

> *"it's interesting when your just thinking about the fact that actually the product was going to completely change how people did that thing so actually testing was quite interesting. Particularly early on in the conceptual stage, it's difficult to ask people about their current behaviour and then and them infer what it would be like with your product"* - (P9)

This initial market selection was based on company background allowing them to work in a sector for which they have experience and a customer base. From this point the design lens was firmly focused at an activity level working closely with users to understand the activity from different perspectives and to design a product that could add value by improving the activity experience.

4.5.3.2 Company background

In terms of company background, some of the participants expressed a fairly balanced approach across the core IoT elements of physical product, data and software, this was particularly prominent within the startups specifically founded to create an IoT related device or service. However, for a number of the participants there was a primary focus on one element, with limited skills being demonstrated in other areas. Thus resonating with the work of Lee et al. (2022) in the structure of their model allowing the 3 different angles space to lead. This was a common challenge in cases where the company had an established background within one area and were expanding to incorporate a connected device into their offering. For example, Participants 1 and 4 mention themselves as software companies and see devices as a new business stream that is complimentary to their primary focus.

> *"We are predominantly a software services kind of company, but we are involved in developing and designing connected devices. I guess we're not strictly a manufacturer as such but we could commission manufacturers."* - (P1)

> *"We've always been a software focused company, and so for us we simply saw a need to help our customers, to make it easier for them"* - (P4)

The opposite can be seen with Participant 7 this company was originally founded in the 1980's as a product design agency with more of an engineering focus. This also points to a heavy UX requirement like that suggested by Burkitt (2014).

> *"When we were formed a lot of the things we created were very discrete objects, it was a kettle, it was a toaster, and the only connectivity was electricity, you sort of plugged it in and that was it, and the interface was often mechanical. These days it's more like, we're still designing physical things but it's more of an experience, it's got multiple elements"* - (P7)

It is worth reiterating that Participants 1 and 7 are agencies that service clients rather than end users directly. In contrast to these elements and client focused approaches Participant 9 is a start-up with a background in consumer IoT. The project being discussed is their second device which is being released to the same market segment as the first product. In this case the project focus is much more balanced with the user as a primary focus from the start.

> *"There was a little bit of a sense that it might be quite sensible to look at a shared target audience. It was a bit of a mad first product in that there wasn't really an established market and so actually it could make our lives a little bit easier by potentially targeting a similar person with our second product but also going into an established market."* - (P9)

In this way company background can be seen to influence the design approach. Firstly in a similar way to the occasioning of the project the initial focus of the work is influenced by the preceding work with either the software, hardware or user activity as the primary view and the most well known area at the start of the project. Secondly this background element will also influence the available skills and setup of the team.

4.5.3.3 Roles and Resources

For some companies who's primary focus is IoT they have all the relevant stakeholder roles in place within their team (such as, hardware designers, software developers, interaction designers etc.). However, for the majority of the interview participants many of these roles were outsourced either through the use of freelancers and contractors or through the services of a third party company. Where skills were sourced externally there was added complexity reported in relation to the collaboration. For some participants they relied on a network of contacts that they had worked with on previous projects. For example, Participant 4 outsourced the hardware engineering work.

> *"my mate, who is an electrical engineer, a good one, he took the Arduino board specs and all the specifications for all the modules that we're using, and he designed it"* - (P4)

Participant 6 also outsourced an element of the work to a previous contact, in this case it was the backend software.

> *"my backend infrastructure was developed by a programmer that I've dealt with before on a couple of projects, he lives in Perth Australia, we're back to a flat earth, it doesn't matter where they are, it's only time difference."* - (P6)

In other cases skills were recruited as and when they were identified as necessary.

> *"to take a product from an idea to a physical product that you actually need something called CAD files, which need to be done by a professional designer, so we actually hired a designer, who is still with our team today"* - (P5)

In other instances, particularly in the case of short term jobs such as tooling supporting services were sought through third party companies.

> *"we got lots of quotes in for tooling of the product and actually realised that tooling was going to be so expensive, but we found a company in Surrey that helped us to bring, to make a tool, and then we started making the product through injection moulding"* - (P5)

There was a sense in this that an element of learning on the job is needed particularly in the smaller businesses that are just moving into the field of IoT. For example Participant 4 undertook the initial prototyping phases of the design work before passing this to their chosen engineer. Participant 8 also took this approach of undertaking a large part of the design work themselves. In this case it was due to a lack of confidence in the available skills of freelancers.

> *"I did a lot of the design, in part because it's cheaper, and a lot because yeah people are just kind of saying that they're voice designers, like what, yeah I used to do the website and I speak"*
> - (P8)

Due to the nascent nature of the IoT industry many of these skills and roles are still developing and being identified. As we can see from Participant 8's comment and from the ways in which companies are entering the IoT market, there are areas where skills are still being developed and best practices within some of the different areas are still unclear. A number of the businesses interviewed indicated an approach of maintaining relationships with other businesses or freelancers where trust in skills had previously been developed through successful projects. For example, Participant 10's company had been sub-contracted by another company on a variety of projects. In this case the two companies worked in partnership to produce a number of IoT products for external clients.

4.6 Chapter summary

The findings of this study highlight the variety of different design contexts within the IoT and showcase the related design challenges and approaches through practitioner accounts of their work. The responses from the interviews highlight core themes of embeddedness, long-term usage and business constraints as key areas in which these challenges arise. To summarise then:

Embeddedness challenges were encountered in areas relating to the physical context of devices. For example, when catering for harsh environments software development work was required to manage data collection and transfer to ensure a level of reliability. In one case different levels of service contingency had to be provided for varying connection speeds and physical device conditions. In another case accounting for the effect of casings on data accuracy became a software challenge. In order to address these challenges it was essential for the different physical and connection states of the device to be considered and catered for within the software design work.

Embedding within sociotechnical infrastructures also presented some key challenges for designers, such as that of users, customers and clients, industry regulations and different layers of the product infrastructure itself. These challenges are in line with those discussed in the literature within section 2.1 of this thesis. Of particular note here is the core nature of these challenges to design work encountered across the variety of projects drawn on within this chapter. A key differentiation identified here between software or hardware products and connected products is the challenge of producing a cohesive user experience across the whole product and service. Tensions were noted in relation to the different approaches of hardware and software design, with hardware design aiming for a level of permanence and software design aiming for agile fluidity.

Challenges relating to the long-term nature of IoT products and services were raised within the interviews. These include power generation and usage considerations, supply chain risks (such as unexpected price, hardware or delivery changes made by suppliers) and modification to deployed systems. While these have been discussed to a certain extent within the academic literature there are also clear gaps to be addressed here (as shown in section 2.1.4). The following chapters of this thesis will further address the gaps through more detailed analysis of the longer-term aspects of IoT products and services, including ethnographic field work observing the modification of a deployed alarm system (chapter 5) and the reuse of data streams to create an advice giving chatbot (chapter 6) as a form of a value-added or secondary service. Two areas which were identified within this chapter as prominent within industry and demonstrated in chapter 2 as areas in which the literature is currently lacking.

Business constraints are the final category of challenges identified within this study. The findings demonstrate how company background, project occasioning and available roles and resources can all influence the approach taken to design work. This also ties in closely to the differing **approaches to the physical** aspects of IoT solution design and development, identified within this chapter. Three different approaches were noted; building a bespoke device, creating a device using off the shelf components, and utilising other devices that are already deployed. **Supporting services** were also identified as a key part of the IoT industry with various platforms and related services being offered to companies who are developing products and services. Many of the design challenges and approaches identified within this chapter differ according to the type of business and the approach to the physical aspects of the IoT. For that reason the following 2 study chapters differ in relation to the control they have over the physical devices. The alarm system modification case study discussed in chapter 5 provides an example of a business which has a large amount of control over the infrastructure. In contrast the advice-giving chatbot case study discussed in chapter 6 provides an example of a product that draws on data from multiple devices which are designed and managed by third parties.

4.7 Study I conclusion

In conclusion, the interview study reported in this chapter highlights relational tensions in a number of areas within the IoT design process. Two notable ones which go beyond lab based and research through design approaches to IoT design (often practised within academic settings), reside within the supply chain (particularly where off-the-shelf components are being used) as well as tensions in the design team itself. While the challenges are drawn out here during discussions about the initial design of IoT products, they relate to the long-term nature of IoT devices and their need for ongoing support.

Within industry, business models are adapting to this change with service approaches becoming more common. It has been argued that the value created in the development of the product is now within the software and data layers (Lee et al., 2019b) rather than with the hardware elements due to their ongoing service nature. Participant 9 (in section 4.4.7.3) describes the tensions between the hardware and software teams as stemming from different approaches. As the hardware team attempts to create a product with a level of permanence that can stand the test of time when it has been deployed, the software team take an opposite approach, creating a minimum viable product for launch and planning for continual updates to the live system to maintain service and security levels. This tension in approaches presents both challenges and opportunities for designers. For example, Participant 9 (in section 4.4.7.3) presented this as a challenge in creating a seamless experience for the user. In contrast, Participant 11 (in section 4.4.7.3) presents this as a design opportunity in his descriptions of using data and software to learn and then change user experiences (of both hardware and software) remotely. From a wider perspective this continuous need to keep software updated presents cost challenges to businesses and in turn increase the risk of additional e-Waste through premature hardware obsolescence Blevis (2007). An important thing to note here is that while the "classic" ubiquitous computing challenges have touched upon these issues of the permanence of hardware and ongoing software updates, for example, through research around security, this has not been thoroughly investigated as an underlying tension within the design process. The sustainability issues arising from this challenge have also not been considered in detail.

Through this increased understanding of IoT design from an industry perspective this study has uncovered some core design challenges to be considered, particularly in relation to the longer term aspects of IoT. This also then provides a foundation for the following ethnographic fieldwork studies; considering modification work to deployed IoT service infrastructures

(Study II) and prototyping a chat interface utilising data from deployed IoT products(Study III).

Chapter 5

Study II - Modifying an IoT alarm system

5.1 Chapter overview

This chapter presents an ethnographic study of a commercial IoT product design and management team with a focus on the design work undertaken on the modification of a deployed IoT alarm system. The chapter is based on a paper previously published in CSCW journal and due to be presented at the 2023 ECSCW conference. The detail presented in this chapter has been re-framed slightly to ensure it fits within the wider context of this thesis.

Within chapter 4, challenges and opportunities were identified by practitioners in relation to the modification of deployed IoT systems. These include: different levels of permanence in relation to hardware and software, opportunities for user experience updates, live testing and field trials, the ability to remotely use data to make service improvements, new service related business models and opportunities for bug fixing. Much of the discussion around modification within the interview data considered the opportunities of using data to improve product offerings after the initial deployment. While these practitioner accounts in the interview study (chapter 4) offered insights into what types of modifications can and cannot be made to deployed systems, a key unanswered question of *how* design teams can practically work with distributed systems as a basis for design, remains. Here the embedded nature of these systems and how that influences the related design work is considered in more detail.

This chapter expands from practitioner accounts of the challenges and opportunities of system modification and delves deeper into unpacking the practicalities of this work through observations of collaborative design reasoning activities within a corporate setting. This empirical study of design for an established managed IoT system, provides a more detailed understanding of the infrastructural design challenges facing multidisciplinary teams working within this space. The findings described within this chapter demonstrate the ways in which Infrastructural Inversion is used to make hidden aspects of the infrastructure visible to various team members as they troubleshoot a problem encountered by onsite engineers, before proposing and fleshing out a solution. Key contributions are made through the identification of the use of notions of elemental states[1] as a way of maintaining the visibility over key tensions identified between the operational and functional aspects of the system to support design reasoning. In addition to this, new responsibilities of professional digital plumbing work are identified.

[1]'notions of elemental state' is a term developed within this thesis to describe how members undertake a form of infrastructural inversion (Bowker, 1994). Drawing on a particular state of one or more infrastructural elements to explore their relationship through potential design scenarios which support their design reasoning.

5.2 Introduction

Chapter 4 raised some interesting design challenges around the sociotechnical infrastructural nature of IoT solutions. This infrastructural nature incorporates different user types as well the different layers and components of the IoT solution itself (Lee et al., 2018). Within the academic literature this is an understudied element of IoT design and is therefore an important area in which to delve deeper with this thesis. While, of course, IoT solutions have been considered as a layered networked infrastructures made up of physical devices linked through software (for example, Costa et al. (2008); Kakkar et al. (2021)), research considering IoT solutions as sociotechnical information infrastructures is lacking. Information infrastructures as described by Neumann and Star (1996) are relational in nature; incorporating human, social and technological elements to make up a system as a whole.

As demonstrated by the interview findings in chapter 4 and the infrastructuring literature (Star and Bowker, 2006) a key feature of information infrastructures, which present very specific challenges for designers working with them, are that of embeddedness into structures and arrangements. While a number of studies in the ubiquitous computing literature have touched on this social embeddedness (for example, Tolmie et al. (2002)) they focus on embedding 'things' into social arrangements, and the implications this has for design and the end-user, they do not consider the implications of the sociotechnical layers within the product and service itself on design work. Therefore, ethnographic studies of practice, such as the one described in this chapter, are required in order to gain this broader view of the sociotechnical relations and the impact that this has on the design and management of commercial IoT products and services.

A further, related, consideration for the design of IoT solutions that was also raised as a challenge within the interview findings in chapter 4, is that of their ongoing service nature, a particularly prominent feature in commercially deployed solutions. With this comes the need for management and maintenance work, similar to that described by Orr (1996) in relation to photocopiers. This type of installation and maintenance work has been explored to some extent within ubiquitous computing, mainly centered around smart homes. For example, discussions around the work of 'digital plumbers' undertaking research deployments into real homes (Tolmie et al., 2010), householders engaging in home networking (Grinter et al., 2009) and professional consultancy work Castelli et al. (2021). These papers demonstrate the role of digital plumbing as a core element in initially establishing IoT systems. There is however a gap in the literature where this relates to professionally managed services, particularly those where installations and servicing are being conducted within wider networks of managed deployments.

Before unpacking the finer details of an in-depth troubleshooting and design session, this chapter will first set the scene by providing a detailed description of the fieldwork setting including the company, the occasioning of the work, IoT alarm solution, project aims, team set-up and the key problem being addressed.

5.3 The study setting

The study took place within a UK based SME that has been providing wireless technology solutions for over 30 years. The company (which will be referred to hereafter as WISP) is well established in the UK IoT industry with 2 core wireless solutions making up the majority of its portfolio. The business model for both of these products involves the ownership of the product remaining with WISP, customers effectively pay for the service, a model sometimes referred to as product-service systems (PSS) Askoxylakis (2018) or sevitisation (Rejeb et al., 2022). The service management level between the 2 products differs considerably with one being installed and maintained by WISP's in-house engineers and the other operating on a self-install model. A key difference here which is worth mentioning is that the self-installed device is sold internationally and is designed to be used anywhere as a pop-up mesh network. Due to it's popularity internationally it would not be commercially viable for the business to operate this as a fully serviced product. Instead they offer a repair service where faulty devices are returned for repair rather than an engineer attending. This approach is also aided by the product itself being portable and able to be removed and replaced from the network easily through a basic pairing approach. In contrast the installed and field engineer maintained product is deployed only within the UK and is connected into a wider static network making it much less amenable to being removed and returned by the customer.

In the remainder of this chapter the focus is mainly on the fully managed product with WISP's engineers installing and managing the IoT infrastructure of the solution as a whole. The reason for this focus is that deployed networks within this product range are static and embedded within wider sites, this makes the installations a lot more permanent than with the mesh networks from the portable product. Another key difference is the complexity of the sociotechnical service offering with more functionality and related services surrounding the product adding to the challenges of modification. More specific product and company details will be provided in the 'introducing WISP and Alert section below.

5.3.1 Introducing WISP and Alert

This chapter focuses on this fully managed product in more detail. The solution (referred to hereafter as Alert), provides property and occupancy related data to facilities management companies. The particular sector in question relates to the management of varied occupancy properties, such as privately owned holiday lets situated within holiday parks and resorts—

properties that need continual oversight by their owners. While there are a number of optional modules that make up the full Alert solution, the main focus within the project described in this chapter is Alert's burglar alarm module installed across holiday lets as part of site infrastructure. Importantly, Alert is not a consumer technology, but is sold as a business to business (B2B) managed service. To this end, WISP acts as a service company too, providing the devices and infrastructure themselves as a service which is installed and maintained by their in-house engineers. It is worth noting that the PSS business model is becoming increasingly common within the IoT industry, particularly within business to business contexts, where the 'ownership' of the devices remains with the supplier and service contracts are used to run and maintain them. This resonances with Orr's study of Xerox photocopier technicians (Orr, 1996) and highlights the professional digital plumber as a key part in the sociotechnical infrastructures that make up these services. Specifically, WISP has a fleet of engineers that install and maintain the entire networked solution, which comprises a Base Station (CIE), Relays (SPT), HUBs and Sensors. Thus the engineers and their work practices can be considered as a core element of the sociotechnical information infrastructure that comprises the Alert solution. Alert is a well-established, mature product that has been operating for more than 3 years and is currently deployed in numerous locations across the UK.

Figure 5.1 shows an overview of the deployed system, demonstrating the location of the HUBs, Relay (SPT) and Basestation (CIE). It also shows the human elements of the system including employees of WISP, the customer (property management company) and the property owners or guests (end users). The devices themselves are connected to the CIE via a radio network with the whole site connected to the particular channel the CIE is set to. An additional channel also exists in the form of a wake-up channel which allows devices to be pinged at specific intervals for monitoring and maintenance purposes.

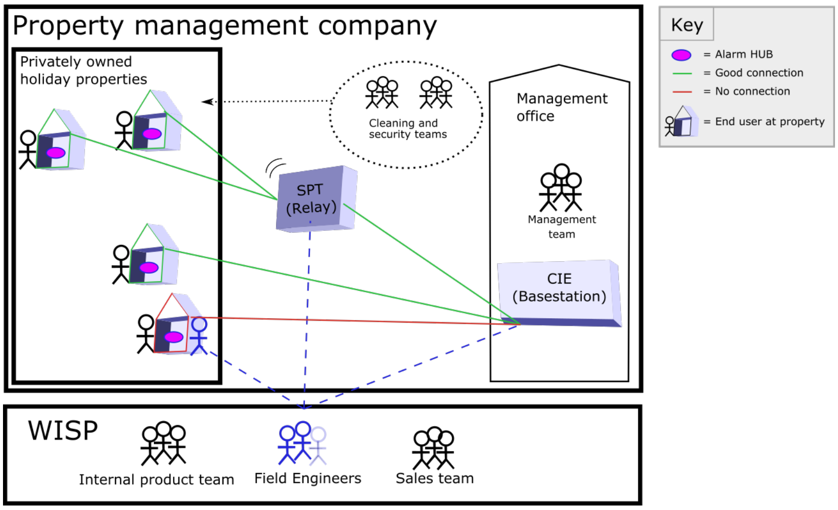

Figure 5.1: Alert deployment within a network of holiday properties

5.3.2 Recruitment and access arrangements

WISP were initially approached through the contact form on their website and a series of meetings to discuss the research and establish relationships with the Managing Director, Technical Director and Research and Development Manager followed. It was agreed that the ethnographic fieldwork would take place primarily within the R&D team, with overlaps with other teams also observed as and when they were relevant to the research.

A two way confidentiality agreement drawn up by the university was put in place. This arrangement ensured open access to the site to observe work practices including confidential business processes and systems, although of course ultimately WISP decided what access was granted to documentation and what was permitted to be recorded. WISP were also given the opportunity to review research outputs before dissemination to ensure accuracy of reporting and that confidentiality was maintained, this task was primarily undertaken by senior management and directors. Apart from some limited access to company systems and project documentation, very little restriction was placed on the research.

The research itself took place over a 7 month period with 11 days of onsite fieldwork, supported by interview data and member checking of research outputs. It should be noted, that due to the timing of the COVID-19 pandemic some of the latter stages of data collection were carried out remotely. Video and audio data were collected from observed meetings and formal interviews, alongside photographs and field notes. Field notes were also used to record less formal interactions such as ad hoc interactions around the office, impromptu meetings and informal interviews. During the fieldwork, complex relations between the operational and technical perspectives of the team became apparent. Attention was paid to this during data collection. These elements of the work were further investigated during analysis through a series of data sessions, systematic analysis of the collected data and informal follow-up interviews with key members of the Project Rock team.

5.3.2.1 The R&D team

Figure 5.2: WISP software engineers' desks

The team was made up of four Software Engineers, one Hardware Design Engineer, a Test Verification Engineer, Project Manager and a Research and Development Manager. As can be seen in 5.2 the software developers are a lot more hands-on with the hardware than software developers in a more traditional setting.

The R&D team had an area that made up around one sixth of the whole office building and were separated off from the other teams. The Software Engineers worked together on a bank of four desks while the Test Verification Engineer and the Hardware Design Engineer sat together on another bank of four desks. The additional two desks available to these two were used for storing equipment and devices that were required for their roles.

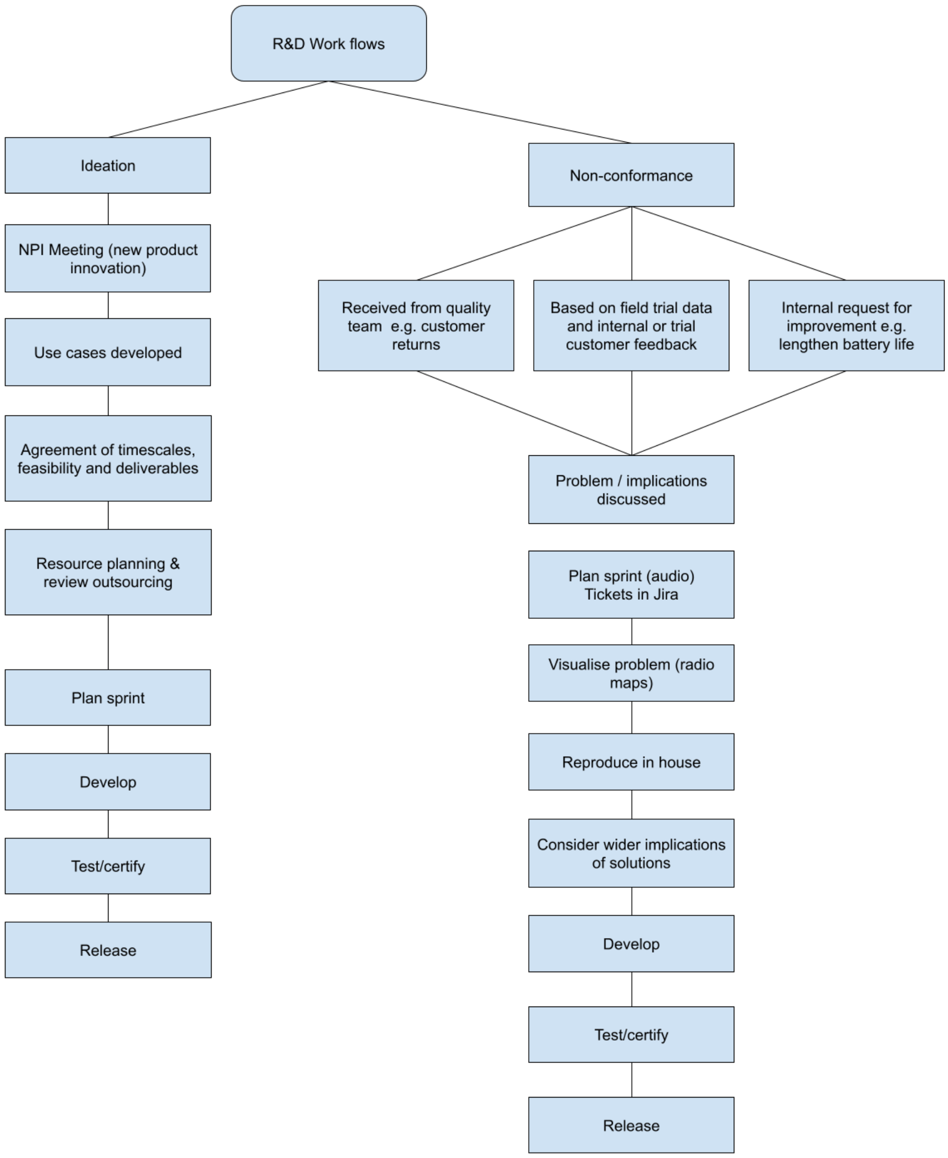

Figure 5.3: Workflows into the team

The occasioning of work for the R&D Team consisted of two different routes as shown in 5.3. The ideation route and the non-conformance route. The ideation route is based on product innovation. Ideas for a new product or modification to functionality of an existing product are initially approved by the management team. After this, to move forward they go through a process of developing use cases, agreement of timescales, feasibility and deliverables through to resource and sprint planning before undertaking and testing the work. The non-conformance route is slightly more varied and unpredictable. The work can come in from a number of different origins and varies widely in terms of urgency.

5.3.3 Project Rock: Updating a managed IoT system

Recent innovation in relation to the Alert product led to a project (referred to hereafter as Project Rock) involving updating the functionality to allow bidirectional communication[2]. This updated functionality meant that the setting of on-site alarms could be carried out remotely, i.e. if the owners or occupants of a holiday let had *not* set the alarm when leaving the property, arming the alarm could instead be done remotely via a cloud-based system without the need to physically revisit to set it manually (as shown in figure 5.4).

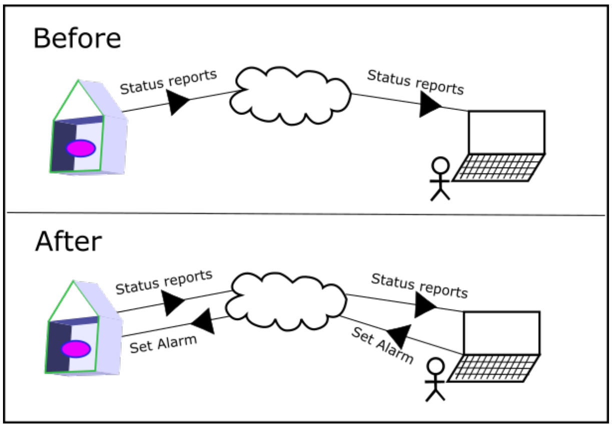

Figure 5.4: Project rock: additional functionality allows remote alarm setting by property owners

To test the updated functionality before full release, the project team had

[2]While adding bidirectional communication was the main purpose of Project Rock, inevitably, as with many commercial modification projects, additional bug fixing and optimisation tasks were also included in the project's code version releases

set up field trials at a number of customer sites. This involved WISP rolling out a new version of the software to some trial sites so they could evaluate the modifications in the wild. This approach gave them the ability to fix any bugs and deal with any knock-on effects of the updates before rolling it out to their entire customer base. The field trial approach was a fairly standard practice adopted by WISP employees as a way of gaining better visibility and testing of any new functionality in-situ with engineers and employees closely monitoring the trials to ensure any unforeseen issues were picked up and dealt with promptly.

The data reported in this chapter is primarily focussed on the latter parts of this ongoing cross departmental project. At this point field trials were well underway and for the most part had proven very successful. However, a trouble related to new installations had been raised by the field engineers in the remaining 2 weeks of the development side of the project. Within this type of facilities management the number of managed dwellings regularly increases, meaning additional installation work within deployed networks is often required—i.e., more alarms need to be put in new dwellings, thus expanding the infrastructure. It is also the case that some maintenance tasks involve an element of installation work, for example, re-establishing connection to an alarm unit following battery replacement. It is for this reason that the practice of digital plumbing (Tolmie et al., 2010) is considered an ongoing concern within managed IoT solutions of this nature.

The specific challenge unpacked in this chapter relates to difficulties faced by installation engineers when connecting up new devices. In essence, the engineers were experiencing errors and inconsistent wait times as the device attempted to automatically find and connect to the correct network channel. This was increasing the amount of time to complete installation work, thus adding cost to the maintenance side of the business; something which if not carefully managed calls into question the financial viability of the service itself. As a result, the project team collaboratively worked towards a solution of enabling the engineers to manually set the correct channel using an RFID tag as part of their installation process. It was thought that this possibility of manual intervention would smooth over these infrastructural issues.

The troubles experienced during installation were initially discussed informally between the Technical Operations Manager (Tom), the Product Portfolio Manager (Phil), and the Test Verification Engineer (Luke) as part of their role in overseeing the field trials. However, due to a lack of clarity over the exact cause of the trouble (as either a software bug or a knock-on effect of a design change), coupled with an urgent need to find a working solution (before the allocated project development time ran out), a project meeting was called with the wider team (as shown in figure 5.5)

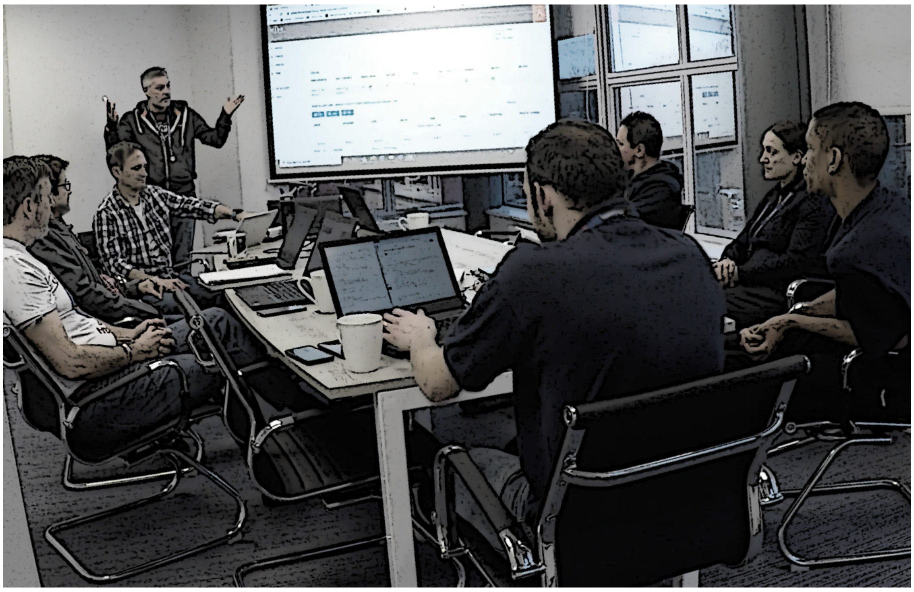

Figure 5.5: The Project Rock team addressing the installation issues reported during field trials

The initial fragments of data presented in this section focus on the resolution of the key trouble raised by the on-site engineering team during the field trial process, i.e. (as described earlier) the problem of alarm devices taking inconsistent periods of time to connect to the network and transmit initial data packets. This is followed by further fragments demonstrating how the project team responded to this infrastructural breakdown through collaborative design reasoning, during a key 3 hour project meeting called to address and resolve the issue.

5.4 Study findings

This section presents the findings from the ethnographic study of the project meeting outlined above. Transcriptions from the video recording of the meeting are presented as fragments throughout the section to provide clarity and depth to the accounts provided.

5.4.1 Trouble in Project Rock

As mentioned earlier, one of the main aims of Project Rock was to add bidirectional communication to an existing live product range. The project was occasioned through the ideation route, with the team being asked to update the functionality to improve the value proposition of the current service. For the purpose of this reporting, the point at which this research joins the cross departmental project team is towards the end of the allocated project time. There are 2 weeks remaining on the development side of the project, the field trials are well underway and for the most part have proved successful. Over the past week or so some trouble has arisen in relation to new installations within the field trial sites. It is worth noting here that within this type of facilities management the number of managed dwellings often increases meaning additional installation work within deployed networks is often required. It is also the case that some maintenance tasks involve an element of installation work, for example, re-establishing connection following battery replacement. It is for this reason that the work of digital plumbing is considered an ongoing concern within managed IoT solutions of this nature.

These troubles were initially communicated informally between the Technical Operations Manager (Tom), the Product Portfolio Manager (Phil), and the Test Verification Engineer (Luke). However, due to a lack of clarity over the exact cause of the trouble and an urgent need to find a working solution, a project meeting was called to facilitate discussion with the wider team. In additional to Tom, Phil and Luke, this included; Software Engineers (Dean and John), R&D Manager (Simon) and Regional Sales Team Leader (Ben). During this meeting Tom was able to formally raise his concerns and initiate work towards finding a resolution. Figure 5.6 provides an overview of how this meeting unfolded.

Following an introduction and agenda delivered by Phil, the investigations into the trouble began with Tom providing an account of what he had seen while completing installations of new alarm systems within the field trial sites. Fragment 5.1 shows Tom's initial description of the problem, delivered for the purpose of highlighting the trouble as an immediate concern to be addressed.

Fragment 5.1

T: So we get a lot of [...] 10 24 type faults and [...] RFID tags not being recognised and flagged as an alert. So you unset it, it doesn't recognise the tag that's associated with that HUB, rather than unset it what it physically does is it sends a HUB alarm, effectively. And that period based on the last one we did yesterday, power it on, goes through all its network pieces, joins the network ok and it took 8 minutes for that data to get from power on to the base station recognising it. We've seen worse than that as well

(Extract from video of project meeting)

The trouble that Tom is describing is justified within his description in 3 different ways. Firstly he describes experiencing errors (lines 1-4), secondly he notes that the period of time that the connection took (in this example 8 minutes), does not align with his expectations (lines 4-7) as an onsite engineer. Finally with his comment 'we've seen worse than that' (lines 7-8) he indicates inconsistencies in this time period.

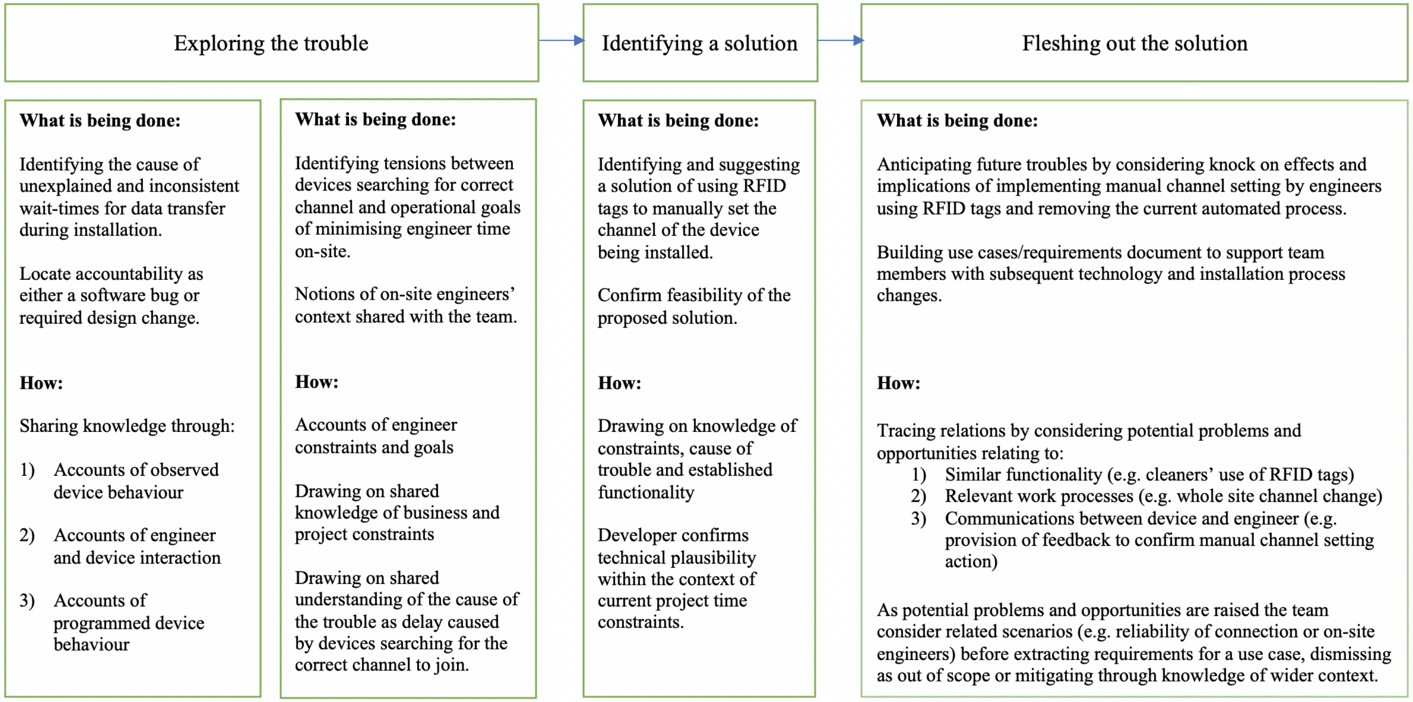

Figure 5.6: Breakdown of how the project meeting unfolded

From an infrastructure perspective, Tom's justifications describe the ways in which the infrastructure became visible (i.e. the point of breakdown) (Star and Ruhleder, 1996) during the work of installation. These visibilities were in the form of error codes, wait times with no feedback and more specifically, inconsistencies in the wait times. While the underlying infrastructural processes remained invisible to Tom the lack of feedback from the device for an unexpected and inconsistent period of time became visibility in and of itself and as such was considered as an unexplained breakdown.

Through the sharing of this situated account to highlight the 3 ways in which the infrastructure became visible to him, Tom makes the point of infrastructure (Pipek and Wulf, 2009) accountable to the team as something he considers as beyond what could, (or indeed should) be worked around by an onsite engineer and something that potentially requires technology change, whether through the fixing of a bug or through redesign work. This account serves the purpose of initiating the search for the exact point of failure and leads to more detailed discussions.

5.4.2 The search for accountability or solution

Based on Tom's account the team agree to further consider the trouble and as a result, the focus of the conversation becomes primarily between Tom (as the representative of the onsite engineering team) and Dean (as the lead developer on this area of the project). At this point it remains unclear whether the trouble is the result of a bug in the code, or the result of an unsuccessful design-before-use (Pipek and Wulf, 2009) change within the project. In their continuing search for accountability or solution, Tom provides Dean with a more detailed account of the trouble. Drawing on their internal monitoring infrastructure to support and add clarity to his accounts Tom uses installation and device monitoring logs on a big screen. Fragment 5.2 shows Tom's more detailed account of the trouble (lines 1-8), which is further supported by Test Verification Engineer, Luke (lines 9-10) who adds weight by drawing on knowledge from his role of internal testing and in-house monitoring of field trial releases.

Fragment 5.2

T: We do see examples of this where you [...] go there, power it on, you'll see it appear, [...] on the radio map [...]. Let's just go back to this page [...] to give you an idea, you'll see [...] the summary bit update so it'll show last contact time [...] and you'll get signal strength, [...], in some instances you'll get a power up message and some you won't, and then that's all you get. You get your power up good to install and then it doesn't do anything else. Effectively it almost gets stuck in that stage as though it's not actually managed to migrate any of the messages

L: I've seen this here, when it gets in that state it's gone walking round the channels

(Extract from video of project meeting)

Within this fragment (5.2) Tom provides a more detailed account of the trouble experienced. He includes details of the step by step interaction between the engineer and the device as well as the use of device monitoring resources, such as logs, to situate it within a wider context. For example, he refers to the device appearing on 'the radio map' [1] (line 2) and the 'summary bit' updating (line 3) within the cloud based device monitoring software. This additional information within Tom's account not only provides more context to situate Dean's understanding of the trouble it also demonstrates the importance of this internal monitoring infrastructure both as part of the digital plumbers object world and as central to Alert's operations. In order to provide a managed service of this nature it is essential that visibility over the naturally invisible elements of the infrastructure is obtained. This network of internal systems supports the day to day work of monitoring, managing, maintaining and updating the Alert solution and serves to connect the in-house and on-site aspects of this work.

Drawing on Tom's account of the trouble, internal documentation of the

[1] The radio map is monitoring software that displays different coloured lines to represent the connection state of devices within a network. For example, a green line represents a device connected to the base-station with a strong signal.

system itself and his wider knowledge of the technology, Dean is able to identify the point of infrastructure from a technical perspective. In fragment 5.3 he describes the conditions in which he would expect to see this type of behaviour being exhibited. In a similar vein to Tom, Dean uses internal documentation about the algorithmic elements of the installation process displayed on the big screen to support his explanation.

Fragment 5.3

D: Yes, what happens is, if, the initial I'm here I want to connect has gone, there may or may not be success in reporting that if it's gone to the SPT, the CIE has received the message somehow and has sent a response, well tried to send a response at the point [...] where the CIE is happy and it's decided yeah this HUB is right and I'm happy for it to be here at this particular point. The CIE will then issue the connect event, which will then trigger the good to install and all that business. But that doesn't mean that the response message has got back to the HUB, so if the response message doesn't get back to the HUB, because it's tried several times and failed or because whatever issue the HUB then will wait for the 10 minutes on that, upon that channel and then it'll move on. That's the response message not getting through

(Extract from video of project meeting)

Dean's description includes the entire technological infrastructure. From the account provided by Tom, Dean is able to explain the data transfer processes at each point. For example, he describes the 'I want to connect' (line 1) message as having 'gone' from the HUB (line 2). Dean goes on to describe the messages going to the CIE (line 3) and there being difficulty in the response message getting back to the HUB from the CIE (line 9). He continues by explaining how the HUB is programmed to respond to this type of connection failure; waiting for 10 minutes and then moving on to try a different channel (lines 11-12). It is worth noting here, the information displayed on the confluence page indicates wait times of 2 minutes between the attempts described on line 10. Within his description he also provides explanation for information displayed within the monitoring systems that is not in line with what is expected in relation to the HUB being installed (line 7). This provides justifications for the discrepancies Tom has described as well as the inconsistency in the time taken for a connection to be established. From Dean's description it is evident that the device (as a non-human actant in the connection process) doesn't have the necessary information about what channel the network it is trying to join is on, it is therefore, undertaking a channel search process when it doesn't receive a response from the CIE. Dean's explanation removes a software bug as the cause of the trouble and indicates difficulty within the network connections in the technological elements of the infrastructure, causing the device to lack the required knowledge to allow it to connect to the correct channel within an efficient and consistent time-frame. While this explanation provides some clarity over what is happening on a technical level, it does not provide a solution for the trouble engineers are experiencing when completing the installations.

In Fragment 5.4 Tom responds to this explanation. To frame his response he explicitly declares his operational perspective (line 1), drawing on his role in the company as Technical Operations Manager to highlight that the current solution conflicts with the goals, constraints and processes of the onsite engineers. Tom highlights time constraints (lines 3-5), and indicates that while he understands the justification for the devices to wait for a message (lines 7-9), the wait time for a non-default channel is '100%' unacceptable (lines 10-12). It is important to note that while he refers to himself in this fragment (5.4) as the engineer onsite using the technology, his management role within the company is to oversee this element of the work. He is therefore in a position of authority and accountability where the operational elements of the solution are concerned. At the same time he is also considered as an internal customer by the R&D team adding further weight to his concerns being prioritised. Further to this the additional information Tom provides about the time constraints on engineer site visits serves to remind the wider team about the maintenance priorities at a business level and to refocus the task at hand on resolving the tensions between the technology and operational challenges of the installation process.

Fragment 5.4

T: I'm looking at it now [...] operationally and [...] that whole process of being able to install them and maintain them and the fact that we do have a limited amount of time for both of those activities. So typically we only allocate 40 minutes for an installation and 20 minutes for a maintenance visit or a repair [...] so my problem I suppose [...] is why some of these. It is hit or miss [...] as to whether they do join quickly or not [...] I get the bit [...] about [...] if it doesn't hear anything within 2 minutes it may elongate that to 10 minutes [...] but I don't have 10 minutes to wait truthfully as part of our process for that to join, and what I 100% won't have if we're not on the default channel is the amount of time that I may have to wait for it to join when it's on the next channel down the line so

(Extract from video of project meeting)

Tom's response in Fragment 5.4 demonstrates that waiting for an invisible process that takes an unpredictable period of time does not fit with goals and constraints of the installation process. The whole project team are aware that in order for the solution to be financially viable the maintenance costs to the business need to be carefully managed. While from a practical level this means efficient installation times it also incorporates minimising the need for maintenance visits, a target that includes battery management. For example, at a business level there is a 5 year battery life target for devices on this solution, that everyone is continually working towards. As was demonstrated in the challenges reported within chapter 4, power is a challenge that crosses the boundaries of hardware, software and infrastructure. Importantly in this case, this focus on careful battery management ensures a team wide understanding about why devices may need to wait for traffic levels to reduce before reattempting this type of non-critical communication, rather than engaging in a continuous operation.

The aligning of goals and values and building of collective knowledge gained from these initial exchanges has enabled the team to identify the exact point of failure. This awareness has realigned the problem space to focus on lack of channel configuration information on the (yet to be connected) device resulting in tensions between the programmed behaviour of the technology and the goals of the onsite engineer. The result of this additional clarity is that Tom now has a fuller picture in terms of the point of infrastructure which enables the process of user-innovation to take place (Pipek and Wulf, 2009). From his experience Tom is aware that the engineer onsite has the channel knowledge that the device needs to complete the operation. While this does not necessarily deal with the issue of connection failure per se, it does account for difficulties experienced when a site is not on the default channel, a point which Tom made strongly in Fragment 5.4 (line 10). Based on this realisation and drawing on opportunities from standards related to the installed base (Star and Bowker, 2006), Tom suggests a solution which capitalises on the capabilities of the devices to receive data from RFID tags (Fragment 5.5).

Fragment 5.5

T: so, [...] it's how I suppose, so something simple that we
could do to maybe fix that hub on the channel [...] we know
that site is on [...] that would be useful [...] I know that our
simplistic brains we're not the clever people, [...] is there
anyway we could do that by an RFID tag, I know that might
seem a bit
D: Yes you absolutely could do that

(Extract from video of project meeting)

As Tom works up to the suggested solution, in Fragment 5.5, he indicates that the engineers have the knowledge of the channel that the device is missing 'we know that site is on' (line 2). He then introduces the solution stating 'we're not the clever people' demonstrating an awareness of crossing a boundary stepping outside of his role as Technical Operations Manager/user/customer and into that of designer, a role usually filled by members of the R&D or product team. In making the comment 'our simplistic brains' (line 3) Tom also shows an acknowledgement of wider contexts and consequences of design changes that he may not have anticipated, declaring in essence his unfamiliarity with the new domain into which he has crossed. The solution of using an RFID tag to configure the channel draws on Tom's knowledge of this as a standard for humans interacting with this particular device. The RFID functionality already exists and is used for logging, activating and deactivating purposes by a number of different user groups when the device is in use. The suggestion itself is addressed to Dean as the person who has the knowledge and accountability to decipher whether or not it is technically feasible both with the current physical infrastructure and within the remaining project scope and timeframe. Dean's positive response to the suggestion (line 6) serves to qualify the suggestion as valid and leads to Simon the R&D Manager initiating a task of 'fleshing out' the solution.

5.4.3 Fleshing out the solution

As the team 'flesh out' the solution they continue to collaborate to work up the finer details of the technology and process changes required to implement the suggested solution. To do this team members self-select to raise questions relating to challenges that need navigating. These questions or statements are then either extracted as a requirement to add to a use case, which Simon records (as the designated note taker for the meeting), are dismissed as out of scope or mitigated by wider context.

In Fragment 5.6 Tom raises one of these questions relating to unreliable connectivity expected during install. Drawing on similar functionality he raises concerns about the potential lack of connection at the point when the RFID tag is presented (lines 1-2). This concern is swiftly dismissed by Dean as from a technical perspective it is possible to complete the process locally without the need for an established connection (lines 3-4). To support his dismissal, Dean draws on different functionality that is also performed within the HUB. It is worth noting, when Dean says that the owner cards are stored in the HUB he is referring to the code that processes the functionality rather than the physical card. This was understood by the team, Dean's response was accepted and the challenge of an unreliable connection state affecting this element of the functionality was not questioned further.

Fragment 5.6

T:	the cleaner one is dependent on the CIE having a connection isn't it. We may not have that connection.
D:	Yes, the owner cards are stored in the HUB so these would be stored in the HUB as well

(Extract from video of project meeting)

As the team continue to flesh out the details of the technology change, connection state continues to be central to their deliberations. This demonstrates how the business goals of reducing the operational costs of maintenance remain central within the design process, from both Tom and the R&D team. Fragment 5.7 demonstrates this in the way that Dean suggests that the wake up channel does not need to be set by the engineers because at the point of configuration the connection with the CIE would be in place (line 6), meaning the device would be in a position to receive that knowledge without the need for a search process or human intervention. It is worth clarifying here, there are 2 channels associated with the devices, there is the operational channel which the team are originally addressing with this and the wake-up channel which is separate and serves the purpose of functionally monitoring for maintenance purposes. When questioned by Simon regarding the relation of the wake up channel to the problem they are trying to resolve (line 3-4), Dean continues to justify his suggestion that they do not gain anything from setting this by RFID as the channel searching algorithm does not apply to this channel, it is configured automatically after connection (lines 5-8). Phil also clarifies here that they can be manually reconfigured referring to the related cloud infrastructure (line 10). Following this conversation Simon overruled Dean's argument of not gaining anything from adding the wake-up channel to RFID tags and suggested they add it in as a fail safe option, in case it is needed in future.

From Dean's initial focus on making changes without 'physically visiting'

Fragment 5.7

D: At the moment you get it from the CIE which means you can just change it without actually physically visiting the [dwelling], surely that's preferable and the only reason you wouldn't

S: but then that's the idea that you can change the channel when it happens [...] that's the problem that we're trying to fix with this

D: but you don't cycle round wakeup channels you only cycle round the main channel. Once it's connected to the CIE on the main channel why don't you let the CIE configure the HUB? Because then you've got access to it. I don't think you gain anything from having wakeup channels on the cards

P: can they be, they can all be manually configured can't they

T: yes

(Extract from video of project meeting)

the dwellings he is demonstrating an awareness and alignment to the operational business goals of minimising maintenance costs by allowing work to be done remotely where practicable. He further supports this with technical knowledge of the differing functionality between the operational and wake-up channels. With the wake-up channel configuration happening only after the connection has been established he is working with the assumption that automatic and remote configuration will be possible. This highlights the central nature of notions of connectedness as a resource for design decision making in this case. Dean is basing his argument on an understanding of the sequential order of the installation process and the changes in connection reliability throughout. From a technical perspective failure in the connection is what originally triggered the point of infrastructure, by drawing on notions of connectedness in this way the team are essentially assessing the likelihood of infrastructural visibility (i.e. a breakdown). He shows trust in the connection state thereby dismissing it from a technical point of view and indicating it to be preventable from an operational point of view. When Simon questions this and finally overrides Dean's dismissal of the suggestion to include wake-up channel on the RFID tags, he is both showing a distrust of the connection state in terms of time to configure and an understanding that there is likely to be an engineer already onsite at the point of configuration, thus dismissing Dean's justification of reducing the need to visit the HUB. This further highlights the tensions and complexities between these two infrastructural notions of connectedness and on-siteness.

Fragment 5.8

T: So what I would like. So I want part of an install process to be, select the RFID tag for the site frequency that we physically want it to be, so that's point 1 so that's fine isn't it. I'd also like it to stick on that channel unless it's told otherwise to not stick on that channel, would be my preference, so once you've set that it stays on that. So to counter that then, if we then subsequently needed to do a site change obviously I don't want to manually do that so, some how, in terms of when we change the CIE frequency it needs to push something out. So that's the, so lets say we've got them all on channel 4 [John], for whatever reason and then we find that actually we might need to change that for whatever reason I don't want to manually go and change a thousand nodes
J: no
D: you want a message to say
T: so you want a change message or something like that don't you
J: yeah we're relying at that point. You're choosing to change channel because at that point the channel you're using you have problems with
T: yes
J: you're relying on using that channel to get the new information
T: you are, totally understand that yeah
J: which could be problematic,
T: it could be problematic

(Extract from video of project meeting)

As the fleshing out process continues the team's focus remains on reducing the onsite maintenance costs alongside the challenges of connection reliability, whilst providing support for the digital plumber. In Fragment 5.8 Tom draws on his knowledge of the on-site and off-site maintenance processes to think through the solution to identify any additional technology requirements and procedural concerns from an operational perspective. He makes this thinking accountable to the rest of the team by talking through a scenario of an install process with the RFID tag (lines 1-3), along with his expectations of the system behaviour to 'stick on that channel unless it's told otherwise' (lines 3-4). He then presents a 'counter' scenario in which he would like to be able to change the channel remotely (lines 6-10). Tom raises the concern that in this scenario it would be inefficient to make this change manually, he adds weight by giving an example of 'a thousand nodes' (lines 11-12) – a figure that is not unrealistic with this particular product. Dean and Tom then move on to discuss the technology requirements that would be needed to action that change remotely (lines 14-15). At this point, John raises concerns based on the premise that the likely reason for changing the channel a site is on would be in relation to the connection on the channel they're 'using' being unreliable (lines 16-17), it would therefore be potentially 'problematic' to action the channel change in this way (line 21). Tom acknowledges that he understands it could be problematic. However the option is still considered worthwhile as it may reduce the number of nodes that require a manual visit.

Within fragment 5.8 Tom asserts his role as internal customer in the way that he states and requests his technology change requirements for the installation process as wants, desires and needs addressed primarily to Dean and John. While he acknowledges John's concerns that there could be challenges and problems with the suggested approach of allowing a forced remote channel change, he is very clear that his priority (in line with his operational role) is on reducing the need for onsite visits to 'manually change a thousand nodes' (lines 11-12). Within this requirements statement Tom again draws on the three core notions of on-siteness that are central to this process, on-site installation and maintenance, off-site maintenance, and minimising the number of required engineer visits. John (in his software engineering role) takes the technical perspective of assessing the connection state in relation to the reliability of a successful execution of the requested functionality. This tension between the two perspectives further highlights the design complexities related to managing the operational elements of solution maintenance within the limitations of the technology itself.

In addition to Tom drawing on notions of on-siteness to assess the requirements and impact of technology changes, the software engineers also use this approach. In Fragment 5.9 John considers a scenario of a HUB battery going flat and requiring a maintenance visit. He suggests that after the battery change the engineer would use the fob to select the channel again when they reinstall the HUB (lines 1-2). While John is drawing on his own knowledge of the on-site process he addresses this to Tom as the authority in this domain. Tom confirms John's assumption by stating that they could 'work that in' (lines 3-4) to the maintenance activity as part of the standard work protocol.

Fragment 5.9

J: if the HUB battery went flat and someone is revisiting it, I suppose they'd use their key fob then wouldn't they?
T: the key fob is part of the maintenance, we could work that in so it's part of the maintenance activity.

(Extract from video of project meeting)

From this fragment (5.9) it is possible to further unpack the relationship between the technical and on-site perspectives of this design process and the way in which responsibilities and accountabilities are passed between the 2 core infrastructural elements of technological functionality and maintenance work process. From John's perspective he is identifying different scenarios in which a software solution may be required over a manual one. He addresses his statement to Tom specifically as the person with both the knowledge and accountability to confirm or dismiss this in relation to the on-site process of the engineers. Tom demonstrates this authority in his response stating that 'we could work that in'. This response demonstrates how Tom is also redesigning the onsite process of the engineers to work with the technology changes being made. In this case, as with the initial installations, Tom takes on the responsibility for dealing with channel setting on re-connection as a human process change rather than technology led.

It's worth noting from these exchanges that the key fob itself is both a new physical tool for the digital plumber and part of the information layer of the infrastructure itself. Its purpose is to transfer knowledge in the form of data from the on-site engineer to the software on the HUB. Essentially providing a link between the between the maintenance work process and technological layers of the Alert solution. While it is central to the design change being made by the team, it is not a central feature of the design process and is not treated as an object of design in and of itself. As alluded to earlier, the use of the RFID tag as a solution in this way is drawing on built in capabilities of the devices, effectively embodying standards that already exist within the current solution. It is therefore, the surrounding work and software processes that are the subject of change.

From here the team move on to considering what type of feedback will need to be presented to the engineer when the new process and functionality is executed. The focus of this action confirmation remains on the HUB itself responding to the receipt of channel information from the RFID tag as an LED flash pattern, again embodying a standard as something which the device is already capable of. Fragments 5.10 and 5.11 show the final stages of the design discussion as the meeting begins to draw to a close. Due to time constraints on the meeting, the task of completing detailed use cases for the R&D team to work from has been taken on by the Phil (project portfolio manager) and Tom (technical operations manager) as a task to be completed outside of the meeting setting (Fragment 5.10, line 1).

In Fragment 5.10 John raises some final concerns about the flash pattern as a feedback option. He draws on both the installed base in relation to other interactions with RFID tags and the HUB (lines 4-6) and consideration of the context or situatedness of the on-site engineer 'is it easier to hear beeps than see flashes?' (lines 10-11). In raising these questions John prompted further discussion regarding the content of the feedback, by asking the team to focus on the context of the engineer. Within this fragment (5.10) John also makes the development work accountable to the team by stating that currently ‘any interaction with a fob results in a beep’ (line 4) and a red flash (line 6). In highlighting the current functionality as having both audio and visual responses he demonstrates that development work is required to build upon the current base and that beeps and flashes, as standard, are both equally possible from a technical perspective. This prompted a further discussion about how many flashes or beeps there needed to be in relation to the selected channels.

Fragment 5.10

P: We’ll get you [...] simple use cases for the RFID piece, this afternoon
J: You’ve [...] briefly gone for flashing, what about beeping?
P: Beeping flashing yeah, or both we’ll sort of talk it through with the guys and then
J: Because at the moment any interaction with a fob results in a beep doesn’t it? at the moment that’s your confirmation and I think you get a Red flash?
L: Red flash
T: You get a red flash
J: So would you want it beeping like 1 to 10 for whatever the channel is you’ve fixed or do you want it flashing? Is it easier to hear beeps than see flashes?

(Extract from video of project meeting)

In Fragment 5.11 Tom draws on his knowledge as a member of the on-site engineer team to note that the engineers do not require knowledge of the wake up channel setting at the point of install (line 1). Phil again suggests that they will put thought into this outside of the meeting context and will report the requirements back to the wider team (lines 3-5). However, John persists in his exploration, drawing on his knowledge of the internal monitoring systems when he states that it needs to match the channel number displaying on the ‘cloud’ (lines 6-7) to avoid a ‘disjoint’ (line 11) between the engineers’ knowledge, current confirmation methods and the visual elements of the new RFID based solution. Interestingly, Tom’s initial focus is the number that goes on the physical tag to inform the engineers of which channel they are setting it to. While Phil’s comment refers to the interaction and feedback with the device itself, and John’s comment to congruence between the device and the monitoring infrastructure.

Fragment 5.11

T: They don't care about the second channel it'll be whatever the primary channel is that's the number that needs to go on the tag
P: We'll walk you through, how does it get into the mode, what does it look like when it goes into the mode and what interaction do we want to say in terms of confirmation of channel
J: Yeah, it wants to tie up with the channel number that you see on the cloud for the CIE or SPT
T: Correct
P: Yeah
J: Otherwise that will get confusing. If you're saying I'm choosing pair 1 2 or 3 then the channel is set to 7 there, there's a disjoint there.

(Extract from video of project meeting)

The differing object worlds apparent fragment 5.11 demonstrates some of the complexity involved in these design sessions. It shows how design reasoning incorporating different forms of interaction between hardware, work processes and supporting software, can be achieved through the roles and responsibilities of varying stakeholders with an overall focus on achieving consistency across the different interaction points. The members make visible their differing accountabilities and object worlds as they collectively map the interaction points from the identification of the correct RFID tag through making the action on the device and receiving feedback from both hardware and cloud based monitoring systems.

It is worth noting, following this design session, the solution was successfully implemented within the project time-frames. The only unforeseen challenge that came up for the development team was in relation to other modules (i.e. devices within the same system). As a managed modular system, reuse of code bases is a focus to ensure clarity and overhead reductions in relation to maintenance and updates. One of the devices that makes up part of the modular system did not have RFID functionality built in. This raised the additional challenges of how to deal with an incompatible device. As it was not an option to make hardware changes to comply with the changed functionality it was necessary to silo some of the code-base to ensure the automated channel search was still available in this instance.

5.5 Chapter summary

The challenges identified within the industry overview in chapter 4, alongside the literature review in chapter 2 highlighted a gap in research in the longer-term nature of the IoT. These findings in chapter 4 demonstrated both challenges and opportunities of making amendments to deployed IoT systems and infrastructures which raised questions around how the related design work might unfold when working with a fully integrated product-service system as an installed base. This study builds on the findings in chapter 4 by taking a closer look at some of the challenges of modifying a complex sociotechnical infrastructure of this nature and the ways in which invisible layers and processes can be brought to the fore. In particular, through unpacking a trouble shooting session occasioned from an infrastructural breakdown resulting directly from a design change made during modification work. From this, demonstrations of infrastructural inversion (Bowker, 1994; Simonsen et al., 2020) have been presented as a method used by the members of the setting to support their design reasoning.

This can be seen in the descriptions of the team's exploration of the problem. During this phase they begin to develop the core notions of elemental states central to the design problem. Based on the collective knowledge that the shared goals and values are 'establishing a connection' and 'efficiency of the operational elements' (i.e. time engineer is required on-site), the team develop notions of connectedness and on-siteness. These are then drawn on as resources for design providing a framework for the team to anticipate and assess potential impacts as they **trace relations** to flesh out the solution. These notions are directly related to the tensions between the installed bases of the technological process for establishing a connection and the work process of the on-site engineer surfaced during the first stage of the meeting. By drawing on opportunities and limitations of these installed bases (Star and Ruhleder, 1996) these notions of elemental state are used to support design reasoning through continually foregrounding, thereby providing visibility over the tensions identified during the exploration of the installation troubles.

5.6 Study II conclusion

This demonstration of intentional foregrounding of hidden elements (i.e. infrastructural inversion Bowker (1994)) goes beyond previous descriptions of infrastructural inversion and as such provides a key contribution to the infrastructuring literature. Through this use of infrastructural inversion the team collaborate effectively to anticipate and design in contingency for potential future breakdowns of the sociotechnical infrastructure that is central to their IoT product service. The anticipation and contingency planning for potential infrastructural breakdowns was raised as a key challenge for IoT designers within chapter 4; For example, finding ways to account for potential disruption resulting from installations in harsh environments, through the use of software algorithms and variable levels of data fidelity (discussed by participant 10 in section 4.5.1.1).

In addition this chapter also elaborates on the role of the digital plumber within a commercial design context through the provision of detailed accounts of their work. This contributes directly to the digital plumbing literature Tolmie et al. (2010); Castelli et al. (2021), and will therefore be further elaborated upon in chapter 7.

A central feature of the findings in this chapter is the demonstration of 2 key design challenges; 1) identifying and navigating relational tensions between the different layers of the product service infrastructure. In particular, how design resources can be generated and made visible through collaborative trouble shooting of a breakdown situation, for the purpose of supporting and situating design reasoning. 2) Infrastructural inversion (through the use of 'notions of elemental states') as a collaborative method for anticipating future breakdowns and supporting the design of contingencies for these in relation to various use scenarios.

Chapter 6

Study III - An IoT data-driven chatbot

6.1 Chapter overview

This chapter presents an ethnographic case study of a commercial R&D project within a large, multinational energy company. The focus of the study is on the collaborative design work undertaken by the team as they designed a prototype of a data-driven advice-giving chatbot.

Within the previous 2 chapters challenges were identified in relation to the reliability and visibility of IoT data streams. This was particularly prominent in relation to the use of sensor related data as an opportunity to improve or add to products and services. Suggestions were made by interview participants (reported in chapter 4) that various types of usage data could be drawn upon by businesses to help them to understand and interpret human behaviour in order to improve provision of services. Building on this the following chapter unpacks the activities of a team as they undertake elements of data-work Fischer et al. (2017) as part of delivering a prototype of an energy-advice giving chatbot within a 2 week period. The descriptions of the work presented here demonstrate the ways in which different team members worked collaboratively to make sense of and organise data within the product-service infrastructure in order to provide actionable and meaningful advice to various types of imagined end users.

Throughout the study reported in Chapter 5 the team drew on methods of infrastructural inversion and notions of elemental state in order to make the sociotechnical layers of the service visible to situate and ground their design reasoning. Here we see a similar need to provide visualisations of the infrastructure, as the team draw on and attempt to provide purchase through adding materiality to the IoT service they are designing. In this case, assumed user motivation, the previous conversation steps and representations of the data-work and relationships between these are presented in the form of diagrammatic representations created by the team as tangible design objects. This chapter will demonstrate how the team turned to decision trees as sociotechnical objects to support this requirement for infrastructural visibility to situate their design reasoning.

Thus building on the work in chapter 5 the study described in this chapter considers a different type of modification. Where the alarm system described in study II was being modified to increase functionality for users, the work described in this chapter is designed to modify existing services by providing an additional product, drawing on data streams from multiple locations to provide more information to users than they are able to get currently. This is achieved through the utilisation of an additional medium to communicate with customers. Another difference here is that the design work discussed within this chapter is looking at a prototyping phase whereas the work in chapter 5 was dealing directly with modification to a live system which poses inherently different challenges.

6.2 Introduction

Chapter 4 demonstrated a number of opportunities and challenges around the use of data being generated from IoT devices to improve and enhance services. Within the literature discussed in chapter 2 we note a gap in understandings around the way practitioners incorporate data science into IoT products (Lee et al., 2022). This chapter begins to address that gap by presenting accounts of the practical accomplishment of members in relation to the use of data from these devices as a design material within a commercial R&D context. This is particularly relevant to infrastructuring work in the way that members pull in data from a variety of different IoT and non-IoT sources. The project unpacked within this chapter demonstrates the ways in which a team visualise and reason about different data streams as they pull them together whilst anticipating user motivation and reactions to the insights they are generating.

The hyped 'vision' for the Internet of Things (IoT) sees large quantities of sensor data being made available from a plethora of ubiquitous connected devices. This data lends itself to the production of secondary services (Lee et al., 2014), also referred to as value-added services (Theodoridis et al., 2013), which provide auxiliary functionality to devices and services connected to the IoT. The practical reality of designing these services, presents some significant challenges for design teams, as they attempt to make sense of human, social activity from heterogeneous data sets. This chapter unpacks the methods used by commercial Digital Research and Development (R&D) team members as they use smart thermostat (ST) data alongside other sources as a design resource to prototype an advice-giving chatbot.

Previous studies in this area have looked at how smart home data can be used, interpreted and accounted for by household members Tolmie et al. (2016) and also how design can support the use of smart home data to provide advice and insights to householders (Fischer et al., 2017). These studies highlight some of the challenges that design teams face when reusing smart home data to design secondary services. This raises the question of how commercial design teams are adapting to these new challenges and incorporating IoT data into their design work.

Before unpacking the finer details of 2 weeks of design sprints to prototype a data-driven advice-giving chatbot, this chapter will first set the scene by describing the fieldwork setting including the company, the R&D team, the project, access arrangements, the business requirements and details of the sprint process.

6.3 The study setting

The company, a large multi-national energy company (LEC), were selected through a process of networking. The criteria for selection was that the company had a team working on an IoT related design project. The team's management were approached directly and a series of meetings to discuss the research, the company setup and current projects followed. A two way NDA was put in place to ensure that confidentiality was maintained at all times from both sides. This ensured that the researcher could gain visibility over confidential business processes and systems. The Energy Assistant project was selected as it was directly related to reuse of IoT data to provide an additional service. The researcher was given access to observe and record elements of the project, including two design sprints with the purpose of providing a workable prototype of a chatbot drawing on energy related data to provide advice to customers.

6.3.1 The Digital Research and Development team

The team are positioned within the company but are given more autonomy over their work streams than some of the more central teams. This is done to create a more innovation focused environment. They are located away from the main building in an allocated area of an open plan office, which they share with another innovation focused team.

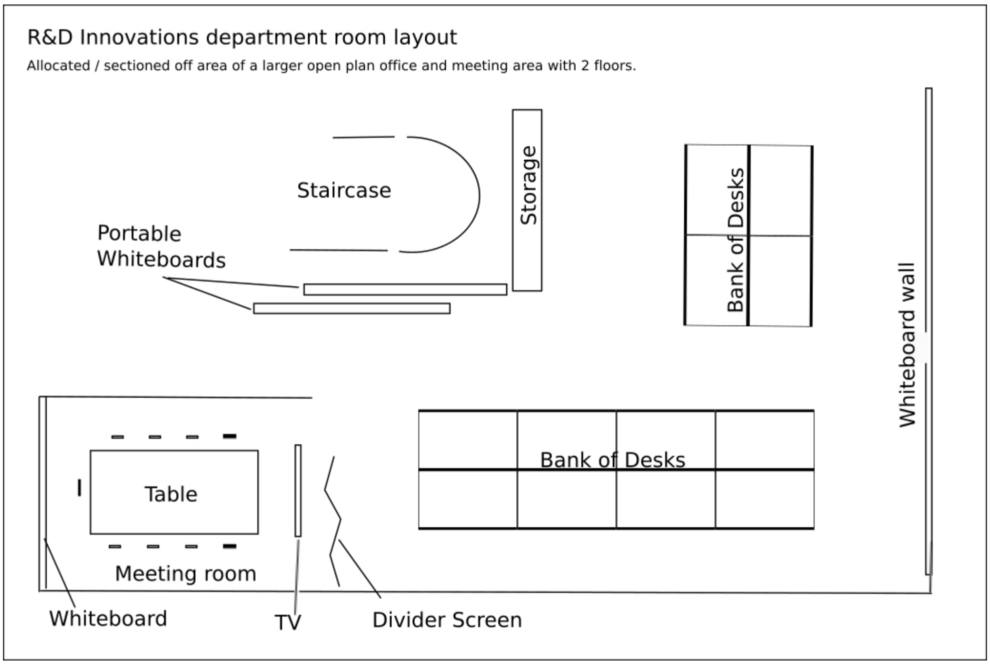

Figure 6.1: LEC R&D team's office layout

6.3.2 Introducing Energy Assistant

Prior to the direct observation of the work an interview was carried out with the Project Manager to gain a deeper understanding of the current state of the project. Insight was also gained into the planned outcomes of the sprints and the project as a whole.

The Project Manager (PM) described the aim of the project as to produce a natural language interface to communicate with and give advice to customers using voice and/or text. He described 2 main elements to the project. One was the *"AI"* that drives the 'Assistant' and the second is the interface with the customer, referred to for this first phase of the project as 'chatbot' or 'bot'. The intention was for the bot to have *"a proper conversation with a customer"* where they could provide advice or assistance to help resolve energy or heating related problems that the customer may be having.

Ultimately, the 'Assistant' was intended to be able to communicate over a number of channels examples given include: SMS, Facebook Messenger, Amazon Echo, Google Home, customer services, live chat. The key aspect that came across as important to the PM was the *"intelligence that drives all of that"*. They were looking to use the data that they currently had on their customers as well as exploring ways to increase those data-sets. The data was being acquired through interactions with customer services as well as through connected devices such as smart meters and smart thermostats. They were also looking to employ external data where relevant such as Energy Performance Certificates (EPC) and historic weather data.

This was considered to be a long-term project that would develop over time and would continue to grow through acquisition of data through the conversations with customers. This continued data gathering has the objective of the 'Assistant' becoming *"even more personalised and even more bespoke"* for the next conversation.

6.3.3 Recruitment and access arrangements

As detailed within the methodology chapter (Chapter 3) the approach to this case study was to use ethnomethodologically informed ethnography to gain a deep understanding of the ways in which the project team navigated a variety of design challenges. A total of 16 days were spent on site across a 7 month period, regular meetings and interviews were held with the management team in order to coordinate the fieldwork alongside the chosen project. Various meetings were attended and observed alongside design work being carried out by the team. This data was supported by both formal and informal interviews with various team members. Over 8 hours of video footage and 5 hours of audio data was collected, alongside 72 A5 pages of field notes. Due to the nature of the research the organisation were able to decide what access was granted in terms of documentation and what was permitted to be recorded. There was very little restriction put on the research, however, there was some limitation on access to company systems and project documentation. The multi-national nature of the company and team meant that there were some conversations and interactions between colleagues that were carried out in members' native languages. In some cases this caused some limitation in relation to the detailed documentation of the work being carried out.

During the fieldwork the central nature of decision tree work as well as constructions and representations of possible end users became apparent, attention was paid to this during the data collection. These elements of the work were further investigated after completion of the fieldwork through a series of data sessions, systematic analysis of the collected data and follow-up interviews with key team members. During analysis, data was organised chronologically with a focus on:

– Resources used by the team

– Challenges encountered

– Decisions made

– Roles that the team adopted

– The use of data streams

6.3.4 The role of the project sponsor

There are two ways in which projects undertaken by the R&D team are occasioned. These were referred to as *'tech push'* and *'business pull'*. Tech push involves the identification of a new piece of technology by one of the team members that they feel may benefit the company in some way. Business pull is the identification of a problem or an opportunity within the business either by one of the R&D team members or as a request from another department within the business. The Energy Assistant project was occasioned by a request from Jenny, the head of the Digital Operations Team.

Due to the nature of there being a specific request from another department the team tried to include the initiating stakeholder in their work as much as possible. Regular meetings and conversations were held between key team members and the stakeholder to communicate the requirements and design specifications that they were asked to work to. Much like other design processes in industry environments (Crilly et al., 2009; Martin, 2012), this approach meant the interpretational challenges facing this team in their design work involved more than just understanding how to best serve user needs. They needed to balance their attention on constructing motivations and goals for intended end users with meeting the requirements of the business and its organisational arrangements. In this respect the team had two types of 'users' to please. Firstly the **project sponsor** (referred to by the team as '**our customer**', '**the business**' or **Jenny**), and secondly the intended **end user** (referred to as '**the customer**' or '**the user**'). In the first instance the project goal was to allow the management and project sponsor to assess whether the product had the potential to be taken further. Therefore part of constructing a sense of user motivation also involved understanding the expectations of these stakeholders (i.e., the business).

6.3.5 The sprint process

One of the key requirements discussed with Jenny in the planning stages was that she could have a prototype to look at fairly early in the project. This would help her team to refine their requirements and to provide feedback to the R&D team. They planned and completed two consecutive sprints to produce a testable prototype that they could give to Jenny. During the two sprints Jenny was invited to attend some of the team's stand up and demo meetings to ensure that she had visibility over the work as it was being done.

The sprint team consisted of three data scientists (Hugo, Neil and Craig), three developers (John, Mike and Andy), an intern (Edie) and a Project Manager (Lee). Andy also took on the role of Sprint Leader. The aim of the sprint was for these team members to focus purely on this project for a pre-agreed period of time. The only exception to this was the PM who split his attention between the sprint and other projects/management related tasks.

6.4 Study findings

This section provides a chronological overview of the 2 weeks as they unfolded. This is first presented in diagram form to add context and clarity to the following descriptions of the work. Figure 6.2 shows the preparatory work of the project management team and the activities undertaken by the project team within the first 5 days of the sprint. Figure 6.3 shows an overview of the activities carried out by the team during the second week (days 6-10) of the sprint. These details are further expanded upon in the following sections and are supported with vignettes of data from the fieldwork.

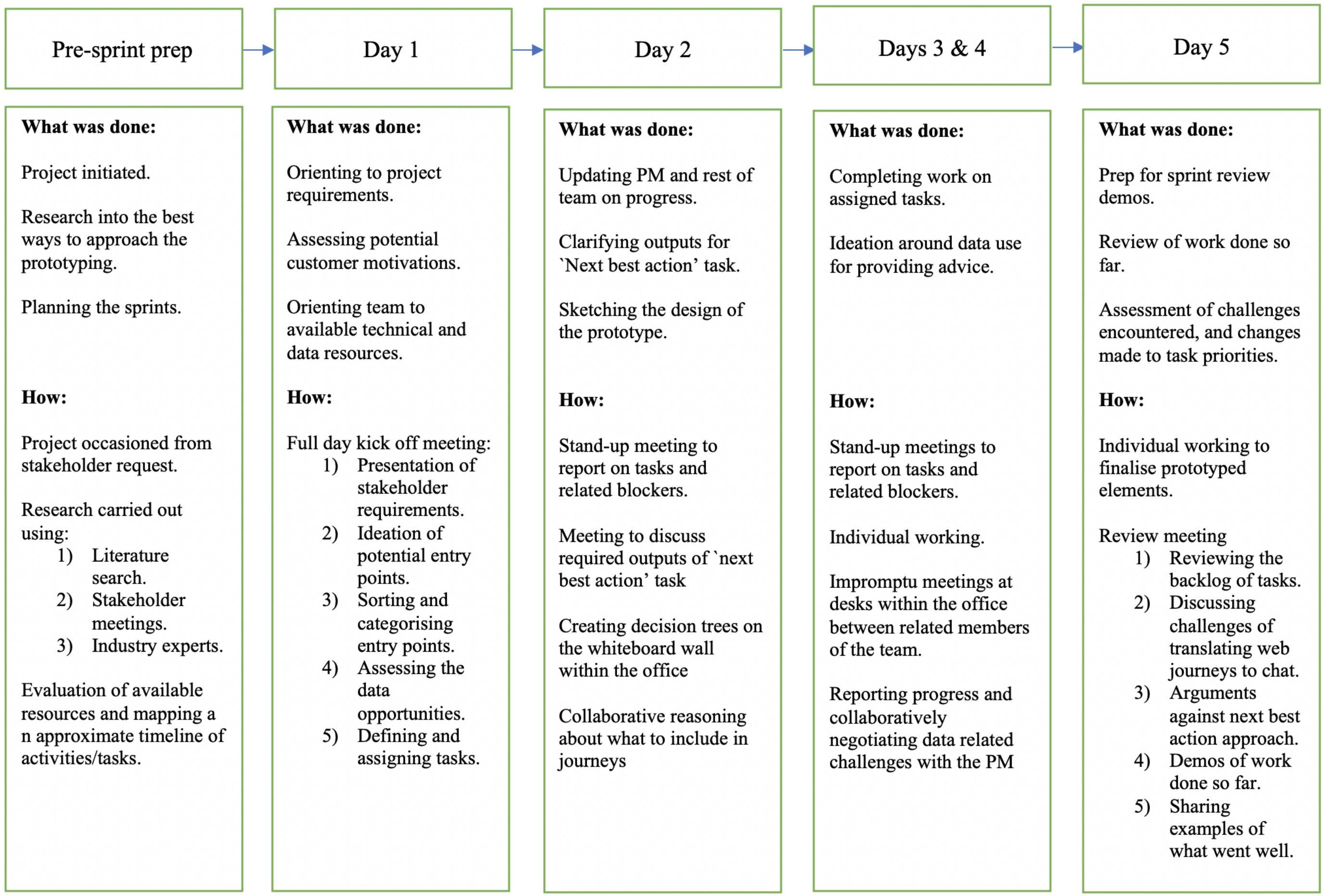

Figure 6.2: Breakdown of the work involved in week 1 of the sprint

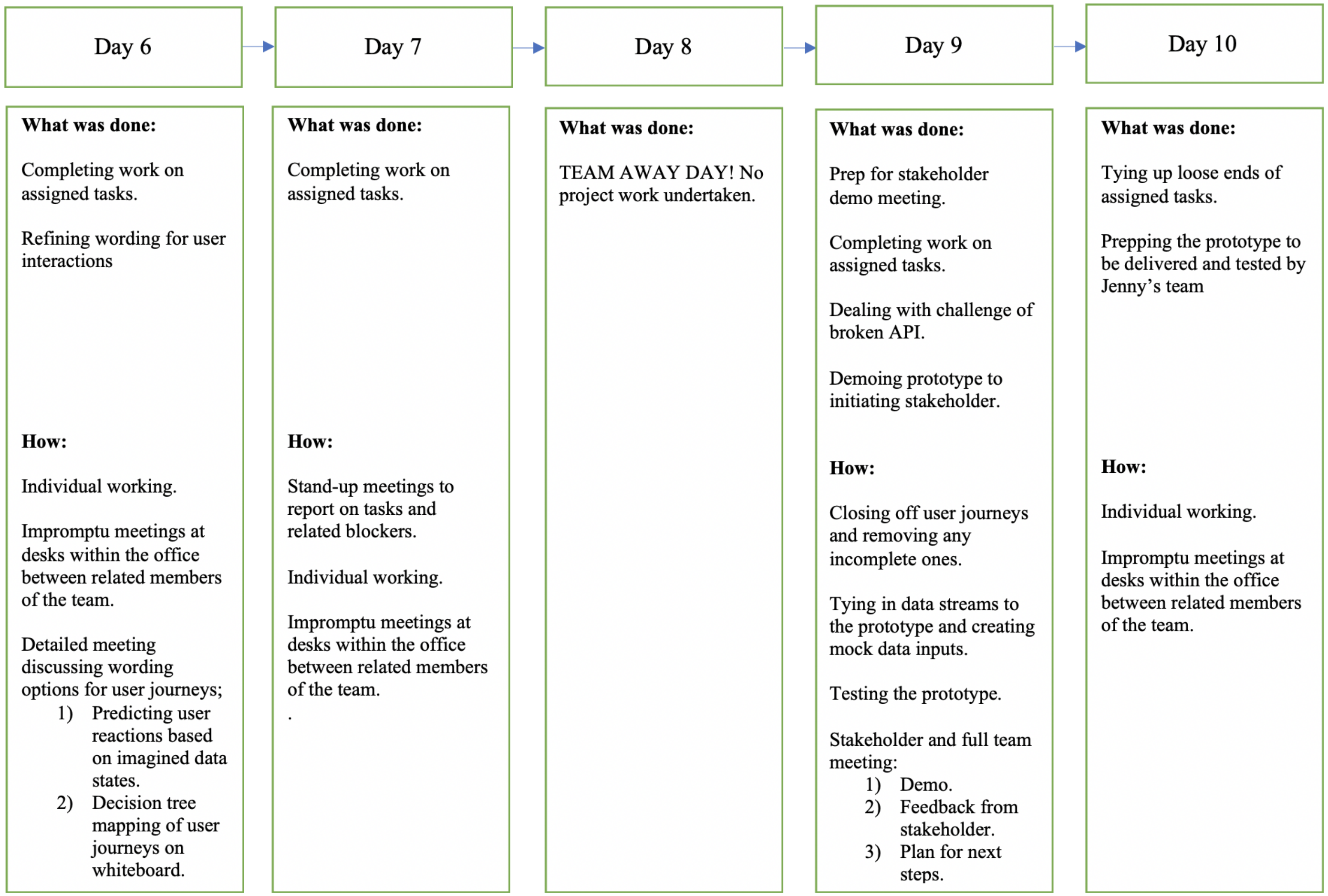

Figure 6.3: Breakdown of the work involved in week 2 of the sprint

6.4.1 Pre-sprint preparations

Prior to the sprint commencing Project Manager (Lee) and Sprint Leader (Andy) held a number of meetings with the Project Sponsor (Jenny) to gather and refine requirements. Some background research had also been done through searches for design guidelines and principles. They had sought out and spoken to *"industry experts"*. However, they communicated that they had some reservations over how 'expert' it is possible to be when it is a nascent technology. In addition to this some analysis research had also been carried out into other 'bots' such as 'news bots' and one created by a fashion company although this appeared to be dismissed by Lee and Andy as *"not really artificial intelligence"*, *"a conversational filter"*, *"just a bunch of decision trees or logic"* and *"not particularly conversational"*.

In his role as the Sprint Leader for this project Andy undertook some preparation work in relation to what he believed could be achieved within 2 weeks of sprints and how the weeks would be organised. This included an agenda for the kick off meeting, collation of relevant materials and resources (such as, print outs of website journeys, reviews of access to data streams and information about the chosen technology stack). This preparation work was communicated to the team within the kick off meeting on day 1.

All members of the sprint team were in attendance: Andy (Developer & Sprint Leader), Mike (Developer), John (Developer), Hugo (Data Scientist), Neil (Data Scientist), Craig (Data Scientist), Edie (Intern, Content Writer). The Project Manager was not in attendance for the kick off meeting, as he was out of the office due to other commitments. The meeting was observed and video recorded as part of this research.

6.4.2 Orienting the team

The meeting began with Andy presenting documents on a large screen to inform the team of the project and sprint objectives. The key objective that was emphasised to the team was to produce a testable prototype within the allocated two week period. In in this way, Andy began by constructing the *framing* of the sprints. He specified a requirement for something that their 'customer' could *'play with'*, thus indicating a requirement for some kind of visible front-end. This approach built stakeholder involvement into the process, staging the possibility of their feedback on the design work. The requirement for visibility of elements during the project placed a number of constraints on the way the sprint was approached from the start, placing the focus more on the user interface elements of the project than on the less visible, but still essential, data-work that would be more difficult to present for feedback. Andy's use of 'play with' also suggests they require autonomy for the project sponsor during testing, rather than offering a structured user testing session or Wizard-of-Oz approach.

In this context the sponsor's perception of the needs of the ultimate end user is key; Jenny, as that stakeholder, is treated by the team as a 'domain expert' in a similar way to that described by Cameron et al. (2018). Her role in this context is to determine whether the chat sequences and product as it is presented to her meet the intended goals. This is not surprising: research has argued a client's perceptions of the end user are influential to the design itself (Crilly et al., 2009; Martin, 2012). It is crucial for the team to gain an understanding of these expectations and perceptions of the sponsor.

At this point, the team did not have access to all the customer data-streams. The sponsor and wider members of the business acted as gatekeepers to confidential end user account data. The team did have a replica system that contained realistic data, albeit on a smaller scale and could assume, as the project progressed, further access would be available to them. This constraint meant they had limited data sets on which to perform their analysis, therefore use of 'fake' data for prototyping was expected. There are some risks attached to assuming that data will be available when it is needed, particularly when it is coming from third party suppliers (noted in the interview findings in chapter 4), as some of it was in this case. However, interestingly, this is a challenge that was not discussed by the team in this project.

The Sprint Leader then went on to tell the team about the two main tasks that they needed to undertake within the sprint, with the first being to translate some of the customer journeys from the website into a conversation. The second task, was referred to by Andy as the *'next best action'*. Andy described this as deciding which way to 'orientate' the user when they interact with the chatbot. He provided an example of when a user says *'I think I'm paying too much money for my energy'* the team would need draw on all the available data to decide how to direct the conversation with that user to produce actionable advice.

The first task given to the team was very structured as they must match the pre-approved journeys currently live on the website. This was accepted by the team and wasn't questioned or queried in relation to what was required or how they could approach it. The second task of finding the 'best action' was more complex. This is something that continued to be discussed throughout the sprint as the team tried to decipher the meaning of the design requirement and its expected output.

During this introductory phase of the meeting the team were introduced to the data streams that were potentially available to them from; the business, the cloud, in home devices (i.e. smart thermostats and meters) and through recording of user interactions with the chatbot for future iterations. Once the team had been informed of the sprint structure, objectives and available resources, they were given the opportunity to ask any questions. This prompted a question relating to the technology stack that was required to be used to build the prototype. The team were advised that the technology stack had been decided in the pre-sprint planning to include; Facebook messenger as the UI with API.AI for the NLP elements, using a Laravel and MySQL backend. Andy suggested that there was potential to employ a tool for *'finding the next best action'* but that the technology for this had not been pre-defined.

This section has highlighted some of the technical constraints that were placed on the design process. For example, having this technology stack predefined before the sprint began, enabled Andy to focus the team on the design and creation of the prototype, without having to spend time researching and choosing technologies. The introductory element of the meeting served to orient the team towards the design elements of the prototype. Once the requirements of the sprint had been discussed and the team's questions had been answered by Andy, the sprint leader, he suggested that they begin the design work together through a joint ideation exercise.

6.4.3 Adopting the end user perspective

No discernible 'end user' was present during this phase of the design process, and as such the team began to construct various end user motivations and goals (drawing on local knowledge e.g., experience of customer data, etc.). The approach of not incorporating end users at this stage was justified by the PM, in a subsequent interview, as "a self-imposed constraint" due to the role of the R&D team in this project being "technology push" focusing on presenting opportunities to help the business understand how new technologies could be utilised. In this section we discuss how the team used ideation and representations of the end user to achieve a sense of user perspective.

6.4.3.1 Ideating and accounting for entry points with end users

The most obvious way in which ideation was used by the team to adopt end user perspective was through the generation of chat entry points / initiating actions from which to map chat sequences and articulate specific goals for end users. For the initial exercise Andy asked the team to put forward suggestions of questions that a user may ask the bot. He stated that he would like the team to think about *'every question'* a user could ask. This approach served to orient the team to the users' perspective rather than the technical perspective.

The task commenced with the team members turn-taking through self-selection to put forward suggestions of entry points. When a suggestion was made by a member the sprint leader added it to the list on the shared document. While it was indicated by Andy that these should be suggestions of things a user may *ask* the bot, the suggestions were not all phrased as questions. Some were worded as statements, for example, *'I can't afford to pay my bill'*. These were not treated any differently to the questions and were added to the document as they were suggested. Conversation analysis points out that questions and answers are a form of 'adjacency pairing' (summons-response or greeting-greeting being two other examples) (Sacks, 1992). The implication that this statement may be seen as a question is indexical of the design context. The team were suggesting entry points to interactions with the advice-giving chatbot; therefore, it is implied that the system will respond to this initiating statement, thereby *making it into a question.*

While many of the suggestions were put forward as stand alone questions or statements some included supporting statements. These were in the form of data-driven evidence or reasoning about the users motivation, for example, reference to previous research conducted through reviews of customer service phone call transcripts. It is worth noting that once the task got underway none of the suggestions were challenged, except for one duplicate, all of them were added to the shared document. After around 13 minutes of brainstorming, a natural break prompted Andy to suggest they move on to the next task.

6.4.3.2 Sorting and Categorising Entry Points

Once the team had completed this task, Andy worked through the document they had created, categorising the entry points. He made this categorising work accountable to the team through providing a running commentary of his work. Fragment 6.1 shows a point at which his categorisation was challenged by two of the team. Mike and John both queried if *'My bill is too high'* was a saving money goal (lines 2 - 3). This prompted a second ideation task (lines 5 - 6) that saw the team working through potential reasons why an end user may enter this statement.

Fragment 6.1

1	SL:	These two are about, saving money.
2	J:	Saving money or bill issue?
3	M:	Or the bill itself?
4	SL:	Yeah why would someone, actually that's a good question!
5		Why would someone say to us, my bill is too high? (Panasonic 30:26- 32:04)

(Extract from video of kick off meeting)

When challenged by a couple of members about whether the entry point 'my bill is too high' related to saving money (lines 2 - 3), Andy acknowledged their concerns (line 4). This prompted a second ideation task of identifying reasons why a person may ask a specific question (line 5), a pause after this question indicated to the team that he wanted them to suggest reasons a user may tell the bot their bill is too high. The team then began suggesting reasons in the same way as for the entry point generation with someone self-selecting and offering a suggestion. Suggestions were then added to the document as a bullet point under the related entry point. In this way the team can be seen to align their thinking to the potential motivations of the customer. This approach provided them with an initial platform from which to provide relevant advice that would meet user expectations. After a long pause with no more suggestions being put forward the sprint leader moved on to the next question on the list.

This move was indicated to the team by reading out the next entry point as part of a sentence about how he was categorising it. Not all of the entry points on the document were expanded upon in the same way. For example, a question around tariff price was described as a *'direct question'*, it was then left as an individual item and was labelled by the Sprint Leader with '[MyAccount]'. This labelling was done without consultation, however, as with the previous meter read example, Andy gave a commentary to the team to make visible and justify his actions. The labelling applied to the item related to the data source required to validate and generate a response for the user.

The Sprint Leader introduced the *'How can I save money'* entry point as *'interesting because we've got stuff to help people'*. This prompted members to suggest ways in which they could help people to save money. Once the team finished producing a list of potential ways in which they could offer advice on saving money/energy, Andy continued to sort the items on the document. He did this by adding labels as described above and by grouping similar items together. While the team all had access to be able to amend the shared document themselves none of them had taken advantage of this. However, Fragment 6.2 demonstrates a change in this behaviour. As Andy was looking through some printed 'journeys' he had been given from the website to find an answer to a question about installation of smart meters, raised by Edie, Mike added 'change habits' to the list of potential journeys under the *'How Can I Save Money'* entry point. The response to this can be seen in the transcript below:

On line 2 the Sprint Leader turns his attention back to the document and notices the change. This prompts him to ask for some clarity on what is meant by the term 'change habits', at this point he is seemingly unaware

Fragment 6.2

M:	((adds 'change habits' to document))
SL:	change habits, so by change habits is that like, changing ((inaudible))
H:	it could be, like by knowing what kind of Smart devices they might have, we could give some specific advice like; we know that you have a smart thermostat and we can see that you have a schedule that consumes a lot ((SL adds more detail to item))
M:	yeah so by change habits, I meant things like you use less energy if you take a shower rather than a bath or ((SL adds more detail to item))
E:	unplug your cables when you are not using them, that kind of stuff ((SL adds more detail to item))
M:	yeah, stop running a server in your house, that kind of thing
E:	of course

(Extract from video of kick off meeting)

of who has added the item so his question is not directed at Mike. Hugo responded to this (even though it wasn't him that added it and no obvious exchange had happened between him and Mike) by providing his interpretation. Hugo's approach to answering the question (lines 3 - 5), drew on his experience as a data analyst in that he considered the potential data sources and inferences that they could make in relation to a customer's heating scheduling behaviour. Mike then responded with his perspective, he included the phrase 'I meant' which indicated that it was him that added the item. Mike and Edie (lines 6 - 9) took a more general perspective than Hugo, considering what the customer may be doing in their house with no mention of data or how they could identify the behaviour they were looking to change. Hugo's approach in this instance was to focus on potential data insights from which to give tailored advice to the customer. In contrast, Mike and Edie took a wider view of providing general information to customers about how they could save energy by changing certain behaviours.

Once the team had finished adding 'journeys' to the entry point 'How can I save money' (again indicated by long pause) the Sprint Leader continued to organise the other entry points on the document. He continued adding labels to items and expanding them by adding sub-items where there may be multiple motivations for a user to ask the question (e.g. moving house).

In summary, there were a number of things going on simultaneously when the team undertook the activity of sorting and expanding on the entry points. Firstly the team were discussing elements of customer motivation for initiating the entry point alongside what the business/data could offer to address or respond to the customer. Entry points were categorised into corresponding item groups based on the type of entry point and the data source(s) needed to address them, with similar or related items moved to be adjacent on the document. Labels were attached to the entry points to indicate either the relevant data source (eg [MyAccount],[Quote Engine]), the corresponding predefined journey (eg [Smart Meter Journey]) or, where there was no predefined data source or journey, the type of journey that would need to be generated (eg [Information], [General Advice]).

Once the team had reached the bottom of the list of entry points Andy suggested that they focus on the 2 entry points of ‘My bill is too high’ and ‘How can I save money’.

6.4.4 From a data point of view

At this point the Sprint Leader changes the focus of the task so that the team were all working from a data perspective rather than the user perspective. He asked the team to think about the data required for continuing the journeys in terms of what checks the back-end of the system could be doing before responding to a user’s request.

Andy then worked through the sub-items listed under the two tasks adding the relevant data streams that can be drawn on as further sub-items. While other members occasionally mentioned data streams or questions that they may ask the user in order to address the point in question, this task was mainly completed by Andy, the sprint leader, with a commentary informing the team of what he was adding and any justification for why it was relevant.

When the task of identifying these potential data sources had been completed Andy moved to the whiteboard to work through use cases in more detail. The example in fragment 6.3 shows how the team worked through the journeys from the entry point as use cases that branch off in different ways depending on the user type and scenario. The term 'branch' (line 14) demonstrates the Andy's use of the tree metaphor to conceptualise the conversations that the team are designing.

Fragment 6.3

SL: OK so that's the things that we should check before asking them for information. Let's say, use case that none of, well you can't check that because I don't have a smart thermostat or smart meter, you have checked but it's irrelevant and you have compared the household but it's irrelevant and you-
H: um what do you mean by it's not relevant when you compare household?
SL: you haven't found information that would lead to us believing that I am paying too much money for my household.
M: So they
SL: compared to the other users
M: so their spending is in line with other households?
SL: yes
M: so at which point would we then be able to assume that the bill is not too high, it's their perception that the bill is too high
SL: yep, yeah actually it's a good branch, there is different stuff but it's like ((writing on whiteboard)) they think their bill is too high, or their bill is actually too high.

(Extract from audio of kick off meeting)

Once the team had established which data streams could be used for the entry points and subsequent journeys they needed to decide on the sequential order of the data checking and the intersection of the user type. They did this through use cases and scenarios. This can be seen in fragment 6.3, where Andy declares a use case and then switches his approach from third person to first person as he delivers the scenario as if it is about himself (lines 1 - 5). This exchange results in a question being raised by Mike that the customer's assumption could be incorrect (lines 14 - 16). This scenario of a customer's assumption of a bill that is too high being incorrect introduces some complexity to the use case and presents some difficulty in how the team can navigate the challenge of successfully meeting the expectations of that constructed customer.

The image in figure 6.4 shows the completed output on the whiteboard. The text towards the top right of the image refers to the 'branch' *'I think my bill is too high'* (lines 15 - 16, fragment 6.3). The red text comprises of different data streams that the team felt would be relevant to answering this query (for example *'check weather'*, *'check EPC'*). This task involved considering and evaluating the intersections of 3 different perspectives. These were the inputs from the user on the interface, the data streams available and the user type.

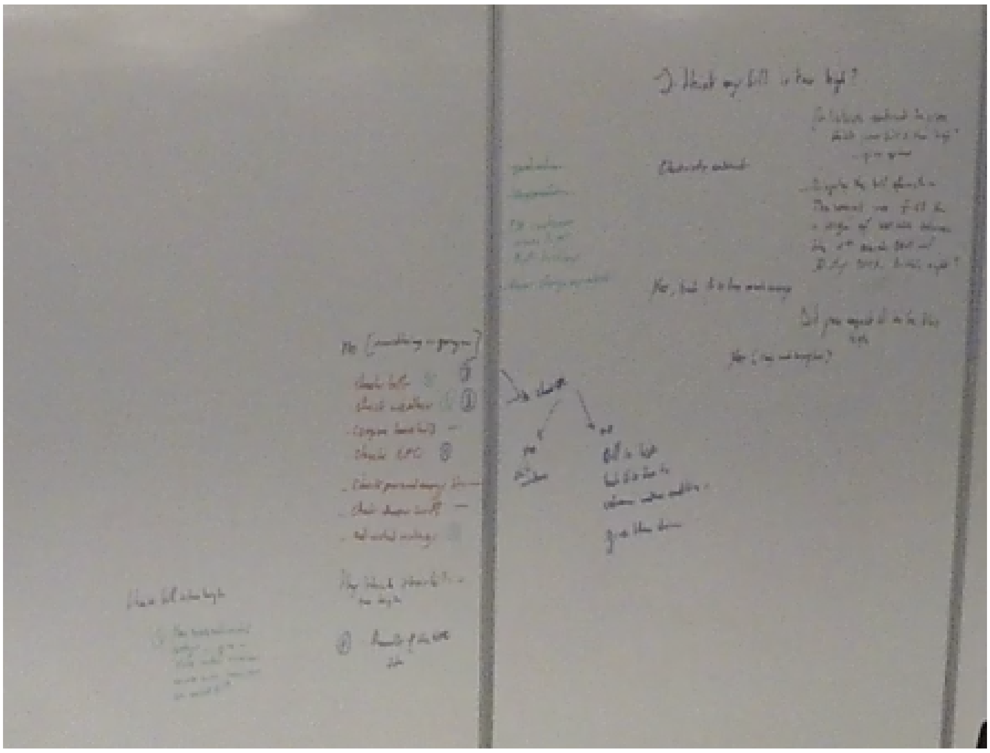

Figure 6.4: Initial journey planning on whiteboard

It is notable here that there is a level of complexity in the planning of the product in relation to visualising and mapping the conversational user inputs and system outputs alongside the use of various data streams to support the advice being given. The team is attempting to juggle the presumed motivations of a user with finding the best ways to use and present the relevant data in order to respond to the query with valid personalised energy saving advice. In order to achieve this they make various design assumptions about the potential indicators in the data and the validity of the customer query, switching their perspectives between user and data regularly.

6.4.5 Define and assign tasks

The final task of the kick off meeting was to start assigning tasks to the different members. Some of the tasks that were assigned to team members were carried through from the morning session, such as the change tariff journey and the next best action. However, some of the tasks were defined after further analysis of the available resources. The Sprint leader worked through the list of data streams on the whiteboard. The team discussion focused on the availability of APIs that would give them the ability to easily draw on the required data. This task involved the team sharing their knowledge on the various resources. This was done either through Andy informing the team that there was an API in place, (for example, MyAccount and Quote Engine) or through him questioning one of the members that he felt had knowledge on the subject. For example John regarding Geo, Weather and Smart Thermostats and Craig regarding the EPC data.

Where members had the information to answer the request they responded with the relevant information. This exercise gave clarification on the resources available to the team and also generated a further task relating to creating an API for some of the GEO and smart thermostat data as it was reported as currently being a collected sample in a database. In addition to the tasks carried over from the morning session and those generated in the data-stream analysis conversation, Andy also added a task of specifying what the bot can do.

The tasks were listed on the whiteboard before being allocated to members of the team. Part of Andy's role as the sprint leader was to define and allocate tasks. He talked thorough them to ensure the requirements were clear before allocating them to members of the team. When assigning tasks Andy asked specific people who had knowledge or expertise in the area. He assigned what the bot can do to Edie, creation of the API's to John, change tariff to himself and the 'next best action' to the 'data guys' Neil, Hugo and Craig. In most cases the tasks were accepted by the recipient with no questions, however, the 'next best action' task was queried as the output was seemingly unclear. Both Hugo and Craig raised concerns about what they needed to communicate to the users in relation to the data checking steps and how they could deliver something without access to all of the data. Fragment 6.4 demonstrates how Andy attended to these queries by providing a more detailed description of how he envisaged the next best action functionality to work through the use of a scenario. This appeared to answer most of the initial questions around the outputs of the chatbot to the user, however it still left questions unanswered in relation to the available data and how the prototype was intended to work if various data streams were not fully available to the team.

Fragment 6.4

SL: this one ((adds star beside 'next best action' on task list)),
is special, this is the most important thing, I think for us.
Finding the next best action when someone comes to us and
says I want to save money, what is [the] next best action
we need to do. Whether it's based on, not necessarily when
the user come and say my bill is too high, but if the overall
I want to save money, what is the best way for the user to
save money, based on everything that we know around him.

(Extract from audio of kick off meeting)

6.4.6 User typifications

Additional clarification was provided by Andy in relation to handling missing data streams. The approach suggested for this was to have different user types based on data fingerprints. Andy confirmed to the team that they would need to 'fake data' and that they should do this though the creation of user types. These were achieved through creating the users in Facebook and then deciding what they would like their data to show and therefore which route each user would take through the journeys. For example, users that were on the cheapest tariff and those that were not. This approach to prototyping the chatbot provided an element of control over the data and outputs that enabled the team to demonstrate how they envisaged the final version working once they had gained full access to all the data streams. It is notable that the team needed to provide a demoable mock up of the system in order for the relevant gatekeepers to grant them full access to the data should the product be deemed 'good enough' to make it to market. The dangers of this approach in terms of the project falling into the 'demo trap' should be noted here (Grudin and Jacques, 2019). Particularly as the project did in fact get through the initial demo but did not get fully scaled up and released due to the heavy workload and management overhead.

Once the tasks had been assigned to the team members the meeting was concluded and the members returned to their desks. At this point it was almost the end of the work day. A small amount of individual and small group planning work was carried out in preparation for the following day.

6.4.7 Daily stand-up meetings

Day two began with a stand up at 9.30am. These meetings were held daily to ensure progress was maintained and any blockers were dealt with swiftly. The format of the meetings was for each member to describe what they did the day before, and what their plans were for the day along with any difficulty or challenges they were facing.

Much of this first stand-up meeting involved the team recapping the tasks that they had been allocated and any plans for moving forward. Key challenges that were put forward here mirrored the task allocation section of the kick off meeting. Specifically revolving around what the expected outputs were in relation to the 'next best action' task, alongside a lack of clarity about what data they have access to. Hugo expressed concern that it is difficult to automate the next best action without understanding what data they have available and all the things they could do from that. A focused 'next best action' meeting was suggested to follow the stand-up with some of the team to discuss these issues in more detail and to clarify what the outputs should be for the team working on this task. The remaining team members went back to their desks to continue working on their individual tasks.

The Project manager, the sprint leader, the 3 data guys (Hugo, Neil and Craig), one of the developers (John) and a further data scientist, on the wider team but not directly involved in this sprint (Thomas) attended the impromptu 'next best action' meeting.

During the meeting the team worked through a document on a large screen that focused on the entry question of 'my bill is too high'. They discussed ways in which the question could be addressed by incorporating the available data against the user typifications. They also discussed potential outputs for this task as being in the form of journey mapping. This meeting led directly to a team effort of journey mapping.

6.4.8 Sketching the prototype through decision trees

Following the meeting a large part of the team (Neil, Edie, John, Hugo and Craig) tried a number of methods to visually represent a potential conversation that a user may have with the chatbot. This needed to incorporate user interaction, data checks and processing that would be carried out in the back-end to generate useful responses. During the meeting the PM requested that the team find a way to do this digitally, however, the team decided to use one of the whiteboard walls as a resource for testing different mapping methods. They would then transfer this to a digital version at a later date. A crucial challenge in this mapping process was that not all customers had the same types of data available. The customer categorisations the team had mapped out included:

- Houses with and without smart thermostats
- Houses with and without smart meters
- Dual fuel and individual fuel customers
- Customers already on the cheapest tariff
- Direct debit and non-direct debit customers
- Houses with and without EPC data

The initial approach used a key to reduce the size of the trees and positioned them within a table to show the customer categorisation as shown in the image in figure 6.5. They numbered the different journeys and used faces to indicate where they could provide actionable information (as the next best action) or where more steps were required.

This was then erased and the team reverted to a different approach. They discussed priorities of when to do the data checks and in what order. For example, should compare customer be done at the same time as EPC checks. This proved to be difficult and this list of data was subsequently erased in favour of another approach, where they incorporated all of the customer types into one decision tree per journey. The different branches of the tree

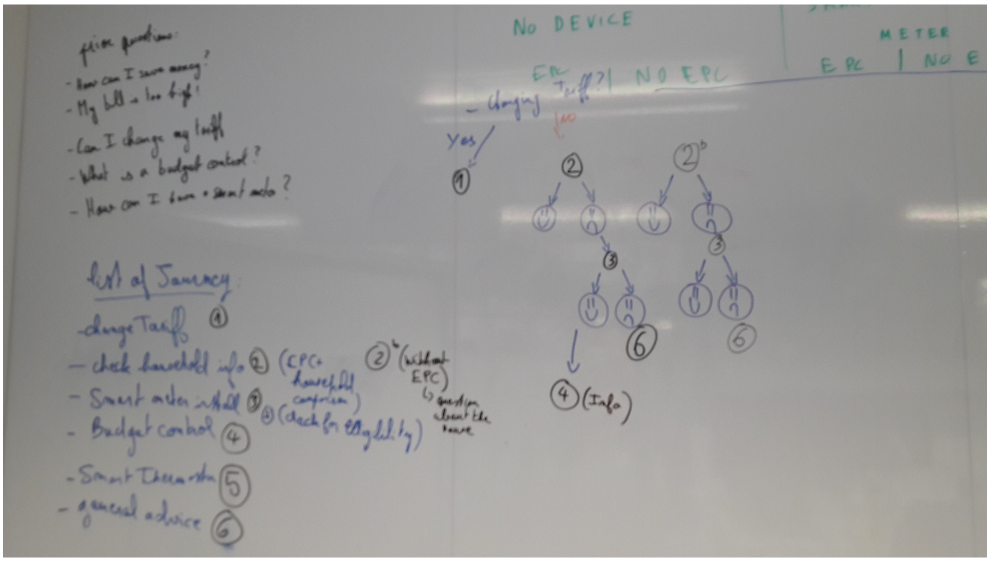

Figure 6.5: Early iteration of journey mapping approach

represented the potential directions of the conversation based on user input, available data and presumed data indicators. These trees started at the entry points of 'How can I save money' and 'My bill is too high', that had been previously identified in the kick off meeting. They then branched downwards with nodes representing either end user input, system output or data analysis through to actionable advice. The team referred to the paths a user could take through the tree as 'journeys', no doubt in reference to the 'user journey' concept common within UX design. Figure 6.6 shows an example of a decision tree created by the team.

As the team drilled down into sub-journeys additional information and branches were added, representing different paths users could take based on responses and data insights. In some cases, such as the 'smart thermostat' and 'change tariff' sub-journeys, separate diagrams were created containing more detail including template messages with dynamic sections for data outputs (similar to those discussed by Kocielnik et al. (2018)) and additional personalisation options. These decision trees were left in place on whiteboards for the remainder of the sprint.

In doing this mapping the team ensured that each of the end user types that had been highlighted were catered for within the journey options and

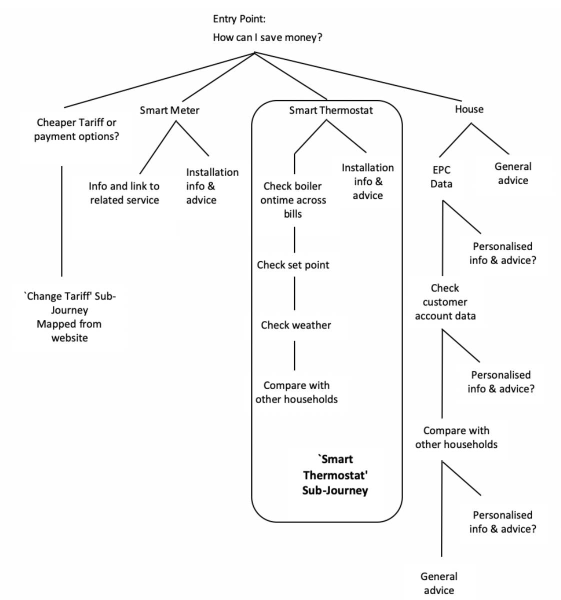

Figure 6.6: Representation of an early iteration of a decision tree diagram

that each path ended in an actionable insight in the form of advice for the customer. This provided the team with a way of designing the flow of interaction with imagined end users, thus situating their design reasoning within the different areas and layers of the product. This approach to gaining visibility over the layers of the product infrastructure is notably different to that seen in the previous case study described in chapter 5. In this case the key stakeholders were not at the table and the interactions here are inherently more complex due to the vague nature of the task of 'providing advice'. Therefore, assumptions needed to be made visible and accountable regarding customer motivation and available data.

In this, the decision tree structure itself anticipated and shaped the process of work as team members began at the initiating statement or entry point and worked through each possible branch discussing opportunities to add value through data and identifying requirements for motivation clarification steps. This process served to maintain the visible context of design decisions as they were being encountered and addressed. This decision tree approach placed data availability as the basis of the conversation creation, thus also mitigating some of the technical challenges around missing or inaccessible data.

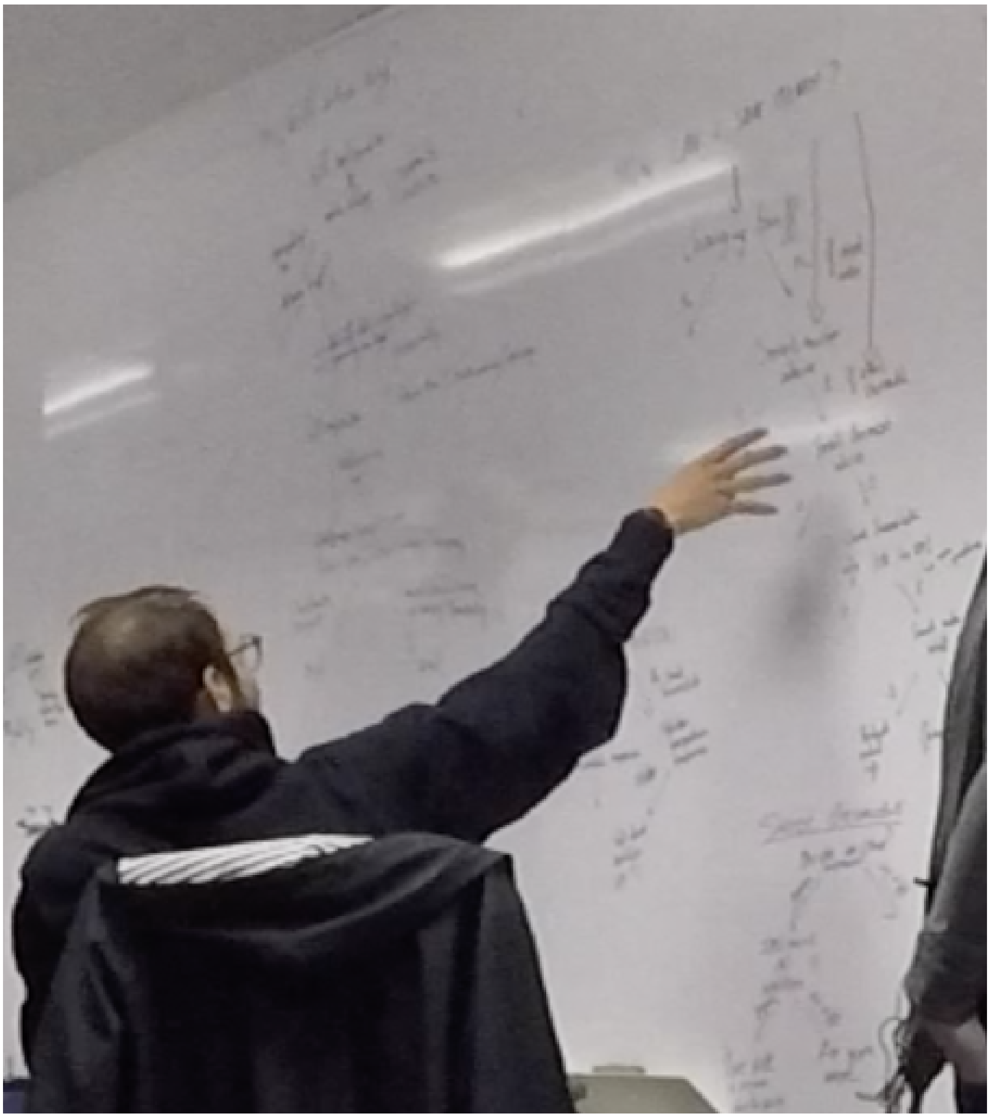

Figure 6.7: Later iteration of decision trees

6.4.8.1 Collaborative reasoning about what to include in journeys

As the team work through the process of filling out the different branches the decision trees they undertake a process of collaborative design reasoning. This reasoning incorporated a process of interpreting meaning from data, in addition to presumed normative reactions of customers and conceptualisations of chat interfaces. The following exemplars demonstrate how the team mapped the data against predicted user reactions and responses to craft a conversational sequence in the form of a decision tree diagram.

One of the challenges surfaced during this task was in relation to clarifying the user's motivation. In specifying the entry points, as the team did in the kick off ideation session, they built some conceptions around how to provide relevant advice. However, as the team worked through each branch of the decision tree they began reasoning about the motivation in more detail. For example, an additional step was suggested to clarify which bill the customer is querying. Hugo suggested this would potentially reduce the risk of collecting irrelevant data from the customer as, for example, the current meter reading is unlikely to help decipher why a previous bill may have been too high. Based on this realisation that they may not have enough information to know which bill the customer is talking about, the team discuss the possibility that there could be more than one bill. By this point the team have switched their focus from minimising steps to adding in extra steps to ensure that they fully understand the customer's query and motivation before attempting to suggest further action. The attempt here was to strike a balance between reducing the chance of potential conversational breakdowns, by ensuring the customer motivation was interpreted correctly, thereby reducing potential frustration by completing the journey with the fewest possible steps. However, due to the limited time to create a complete prototype they decided they could not attempt to analyse and address every scenario, so the focus changes from trying to understand and predict all the nuances of the customers' motivation to trying to keep it simple and ensuring they provided some kind of closure to each journey. Be that actionable advice or general information.

Supporting assumptions about user behaviour with additional data streams

The closure the team were aiming for was that of providing meaningful and actionable advice to the customer to resolve their query. During their data reasoning work of translating sensor data into advice, the team began to pull in other data streams to enable them to decipher and suggest changes to customer behaviour that may have led to higher than average bills. Fragment 6.5 provides an example of how members debate and test a hypothesis of why a set point may have changed and what information or advice they should provide from this insight.

Fragment 6.5

E: I think we need to tell them if there is a difference in set point, then we can check the weather, because most people wouldn't know that.
C: No because it is going to be 20 degrees in your house if it is cold outside or not
J: But if the customer has changed their set point to higher then they will be paying more and we should say that.
C: We should tell them that if they changed their set point they will pay more
J: Yeah, I understand your point so would we need data for 2 months
H: I think what Edie is trying to say is that if there is not a logical link there may be a psychological link

Extract from field notes

Edie initially suggests that if they notice a change in the smart thermostat set point then they should also check the weather data for a change in outdoor temperature (lines 1 & 2) she justifies this suggestion by stating 'most people wouldn't know that'. Craig rejects this suggestion by implying that the two data points do not influence each other. John then pulls this back to the entry point for the conversation suggesting that they should inform the customer that a higher set point means that they will be paying more. However, Hugo then supports Edie's suggestion about considering the weather data within this sequence (lines 8 & 9). He points out that even if there is not a 'logical link' there may be a 'psychological' one and that if a customer has changed their set point it would be worth them checking to see if they can see a reason for it (line 13). Craig pushes back against this suggestion until the team convince him that it may identify a misunderstanding on the part of the customer and a bad habit that they may be able to address through advice.

This conversation demonstrates how the team are going further than just addressing simple use cases by trying to understand how the data they are receiving may uncover some customer behaviour and reveal misunderstandings that can be corrected. They are using the available data to construct a view of the behaviours of their end users, which they can then draw on to support their design reasoning around how to provide actionable advice. This example shows the presentation of a hypothesis that their customers may be interacting with their heating systems through changes to thermostat set points when the outdoor temperature is low. Edie argues that rather than just telling the customer that increasing set point will affect the bill, gaining a deeper understanding of the motivation may help them to provide more targeted advice. Through a series of exchanges the team made the decision to include the outdoor temperature data stream to test this hypothesis by performing an additional data check to look for a correlation. It's worth noting that following this conversation Hugo further investigated the data they had available for this and found a correlation between set point changes and drops in outdoor temperature.

To summarise, the key challenges the team were facing within this datawork were:

- Identifying the customer motivation and considering potential variations based on customer type and situation
- Deciding where the edge cases were; how and when to address these
- Deciding what data should be included or excluded to produce insights that would best meet the presumed customer expectation
- Anticipating what different dataset instances may indicate around customer behaviour and energy use.
- Delivering the information in an optimal order so as to assist the customer in the most efficient way.

- Producing a visualisation incorporating all of the above to provide a basis for discussions and coordination of future tasks

Reviewing journey maps with PM

At the end of the second day the PM initiated a meeting to run through the journey mapping work that the team had been working on. The whole team congregated around the mapped out journeys on the whiteboard for the meeting to discuss their progress (see figure 6.8). Craig sat next to the whiteboard and talked through the two mapped journeys. The journeys were based on the entry points of 'How can I save money?' and 'My bill is too high'. The meeting progressed with Craig presenting the decisions that the team had made regarding the steps in the mapped sequence. This included the data streams that would be checked and the types of responses the system would be giving to the users at various points. As he talked through the decision trees the PM asked questions and responded with his thoughts on what steps should be included and how responses should be presented to the users. There were a few occasions where other members of the team assisted with further information to support or explain decisions however, the majority of the conversation was between Craig and the PM with the whiteboard as the central resource to support the discussion.

When running through the decision trees there were a number of areas where the team were unsure about whether they should use fake or real data and how that may affect the finished product versus the prototype. The exchange in fragment 6.6 is an example of this in relation to the team not currently having access to the customer account data. There is an assumption that if this product gets completed and goes into production the access would be granted, however, whilst at prototype stage the team are restricted. They would like to include a bill comparison between households to assess whether a customer may be paying too much but to do this they would need to be able to compare the bills as well as the households.

Within this exchange Craig was looking for permission from the PM for

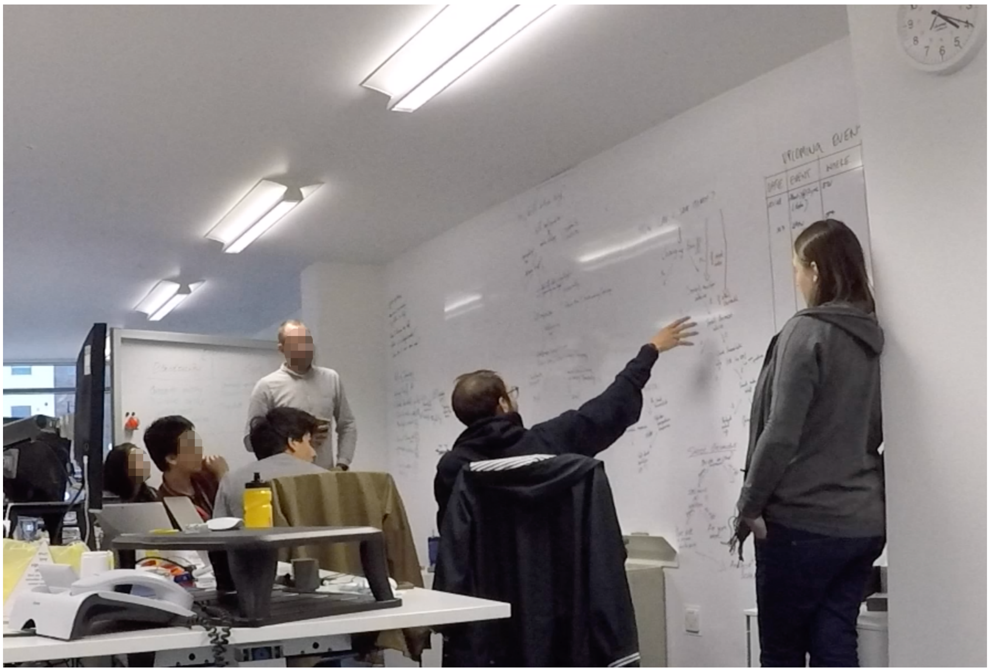

Figure 6.8: Craig running through the decision trees for the PM

them to include a bill comparison with similar households to check whether a customer has higher than average bills (lines 1 - 3) and if it's okay to use fake data to achieve it. The PM didn't address the issue of the bill data, instead he focused on the difficulties of comparing households. His concerns (as expressed in lines 9 - 11), were related to the accuracy of the comparisons due to confounding variables that might impact the data. This debate did not get fully resolved within this meeting. It was left open and the team moved on to address other steps in the journey. While it was not directly blocked by the PM his response of labelling it as quite tricky indicated it was also not approved at this point. This made accountable a requirement for the team to present a more convincing argument regarding the accuracy and validity of their data insights if they wished to include this comparison. The meeting ended once Craig had finished his update of the decision trees and the PM had resolved his queries.

Fragment 6.6

C: if they are paying more we can say okay maybe your habits are bad because for similar houses are paying less or, if they are paying less we can say actually you are quite good.
E: the idea behind that is to check, does the user think that he's paying too much or he actually is. I mean for the saving money if there is any any difference, like a big difference between households around we can offer some other advice or something.
PM: so I guess comparing consumption is quite tricky because we might know what that house looks like but we don't know how many people live in it.

Extract from video of decision tree update meeting

6.4.8.2 Individual and small team working

Much of the work of developing the prototype while still collaborative in nature, involved members working individually or in pairs. By this point on day 3 members had completed the work on the decision trees and had moved on to working on assigned or ad hoc tasks. For example, John took on the additional task of transferring the journey maps into digital format using a mind-map tool before returning to his task of setting up an API. This allowed the members to view the maps on their laptops and provided a back up to the whiteboard. This resource was especially useful for Edie who worked on her own to add in responses and map the conversational sequences into the API.AI system. She worked through the journeys that the team had mapped to create a mock version of the chatbot linked to Facebook messenger on her own phone. As she did this she also made a note of the different customer criteria required to access each fork of the diagrams. This criteria collation would enable the team to create profiles for the relevant user types to allow the stakeholders team to fully test the prototype.

At various points, team members stood up and went over to another member's desk to ask a question or discuss a task. These varied in that sometimes a laptop and/or a chair was taken. This was generally when a challenge had been encountered or where there was overlap in the work. For example, Mike and John struggled with extracting the customers' geographic location from the data that they had. They each had slightly different reasons for needing the same information, as they were working on different elements, however, ultimately the goal for both was to identify the closest weather station to the customer.

6.4.8.3 Making sense of data

During the daily stand-up meeting on day 4, Hugo presented some data-work that he had been doing with Neil the previous day. Fragment 6.7 demonstrates how Hugo and Neil, as Data Analysts, have been looking at their task from the data perspective. This is highlighted in Hugo's opening sentence (lines 1 & 2). The data analytics being proposed is a comparison between households through the use of a leader-board, comparing boiler-on-time with previous months (from the same customer) and looking at the overall boiler-on-time percentage. When presenting the idea for the leader-board (lines 2 - 7) he doesn't go into detail about what the data may mean from a customer perspective and how they may incorporate it into the chatbot. This is also true of the monthly comparison of boiler-on-time (lines 7-9), where little information is provided about how they might incorporate these stats into the conversational sequences. However, when Hugo moves on to talk about the overall boiler-on-time figure he tries to put it into context of how they might interpret that (lines 10 & 11) and how they might incorporate it into the chat sequence to provide 'focused advice' (lines 14 - 18). The PM then responds by suggesting they take a different perspective and consider the delivery of the information to ensure they 'extract the right information for analysis' (lines 19 - 21).

Later in the day Hugo picked up his laptop and approached the PM and announced that he had 'good news'. They walked over to the white-board to continue their discussion. Hugo had found a correlation between

Fragment 6.7

H: so yesterday we were working with Neil, on what kind of analytics we could do with the data that we have. So the first thing that we have done is some leader-board for our customers. A leader-board for set-point temp, outdoor temp and Boiler-on-time. So it could be a daily leader-board, a monthly leader-board or annual leader-board. And you can, it's basically it's available on a weekly report [...]. So the second analytics we were doing was comparing the time of boiler-on with the previous month. So for instance your consumption ((referring to PM)) Lee, for 1 month, so we can say that you're basically a good customer, you don't always use your boiler so it's quite good. But the thing that is quite interesting is that we can, in fact know every-time the proportion of boiler-on-time for the current month for instance, and if it's 80% we can say to the customer directly, please be aware that you use your boiler a little bit too much, if you want to have a lower bill at the end of the month you should address your set point or something like that, and that can be some really focused advice

PM: okay lets spend some time today talking about how we're gonna deliver that information to the customer we need to make sure we extract the right information for analysis

(Extract from audio of daily stand-up meeting)

weather data and boiler-on-time which he explained and demonstrated to the project manager. The transcript in fragment 6.8 shows an extract of the exchange between Hugo and the PM where a misunderstanding around bill periods is resolved and a design challenge is highlighted.

After Hugo and the PM arrived at the whiteboard Hugo proceeded to explain a correlation between the smart thermostat and weather data. The 'good news' that he was presenting to the PM was that he had found a way to check for correlations and that some did exist in the data. As the PM worked through it with Hugo, he questioned the bill periods (lines 1 - 4). This exchange proceeds to elicit the information in question surrounding billing periods use (line 7). Once the PM has confirmed his concerns over the fake bill periods being unrealistic in relation to the live customer data, he proceeded to inform Hugo that the actual billing periods vary, implying that they are not a reliable unit of measurement for comparison. An inac-

Fragment 6.8

PM:	((picks up pen)) OK I need to visualise this. So your smart thermostat data is 15 Jan to 15 Feb
H:	yes
PM:	((writes bill periods on whiteboard)) Okay and then your bill period is what
H:	we look if correlation
PM:	so what bill did you look at
H:	so if there is a bill on the 1st of each month my point will be-
PM:	Okay so I don't mean to take the conversation in a different direction but in most cases we will not have a regular pattern. So what I'm getting at is the bill period varies

Extract from field-notes

curacy within the data analysis could potentially skew the results so it is essential to make sure that the algorithm is sound. While the irregular bill patterns would not impact the calculation at this point whilst they are using fake data, it could potentially cause problems later down the road when live customer account data is incorporated. As Hugo and the PM continue to discuss the potential correlation and what they are going to present to the customer. Hugo is showing the PM data on his laptop, demonstrating correlations between outdoor temperature and higher set points which lead to longer boiler on times and therefore higher bills. He suggested weather data be included in the journey as something that explains boiler-on-time. Fragment 6.18 shows the PM's response to this suggestion as disinterested in the weather data and more interested in the set point data.

Fragment 6.9

PM:	so what about the set point are we also going to talk about that
H:	yes I think
PM:	what would be interesting with this, so we could look at that and say you increased the temperature of your thermostat 6 times. So they overrode the schedule. So we tell them actually that uses quite a lot more energy. So we tell them 'you increased the temperature'. I think that is more interesting because that is behavioural data.
H:	okay

Extract from field-notes

The PM tries to elicit more information about how Hugo wants to present the information and whether Hugo is also going to include the set point data (lines 7 - 10). He then goes on to express his interest in the set point data due to it being ‘behavioural’. Thus re-situating the data-work as incorporating and understanding human behaviour, and tying it directly back to the design brief of providing actionable advice to customers.

These exchanges between the data analysts and the PM serve to demonstrate the different roles and therefore object worlds (Bucciarelli, 1988) at play. As a data scientist Hugo’s role within the team is to look at the data to find opportunities, suggest potential analytical approaches and to set up the algorithms required to tie the outputs into the bot. As such, the data analysts began their tasks by looking at the available data and analysing it for relationships to see how they can augment the raw data to provide more detailed insights. In contrast to this the PM is focused on the end user and the meaning of both the originating sensor data and the insights being provided in terms of the behaviour they uncover or support. The PM’s role is one of an overseer, he doesn’t get involved in the detail of the work and will only take on occasional tasks where there is either a lack of skill or time for the team to complete it. His main task is to supervise by making himself knowledgeable about all the work that is being conducted by the team, assisting with advice about challenges members are facing and making decisions around what will and will not be included in the output of the sprint/subsequent phases. Hugo demonstrates that he understands these roles by initiating the exchanges to inform the PM about some opportunities he has found in the data. He further demonstrates this understanding in the information that he divulges, the dialog is structured so that he demonstrates the current state, gives information about potential opportunities, highlights the challenges and then questions the work he should be doing. This is all supported by the responses from the PM, he listens and elicits enough info to ensure a full understanding, offers suggestions for where to get help for the challenges then gives specific priorities for Hugo to work to. It is notable that the articulation work (Schmidt and Bannon, 1992) described here was physically located next to the decision trees with additional visualisation provided through sketching of data representations (fragment 6.8 lines 1 - 2). This orientation to the decision trees as a means to support and situate exchanges between members was seen throughout the 2 sprints.

6.4.9 End of week sprint review session

The main focus of the final day of sprint 1 was on preparing for the sprint review session. The team had been asked to demo the work they had been doing at the review meeting. Much of the work in the morning was individual work on the tasks that they had been allocated. This also included some ad hoc meetings in pairs and small groups to discuss various details of the work.

The review meeting was attended by Andy (the sprint leader), Edie, Hugo, Craig, John, Neil and Mike (who attended via video call on Edie's laptop).

Andy started the meeting by informing the team of the following agenda and objectives:

- Review the tasks that were assigned at the start of the sprint
- Everyone update the team on where they are at with the tasks
- Demos of work done so far

The objective was to review progress to allow them to further build on their achievements in the following week.

6.4.9.1 Comparing what was achieved against what was planned

The team worked through the list of tasks that Andy had written on the meeting room whiteboard during the kick off meeting. As he read the tasks out he added the items to a document on screen. Andy referred to this as running through the backlog. The identified tasks were:

- change tariff journey
- working on the entry points
- what the bot can do
- find the next best action
- narrow down the action
- get the data that we have behind an API or some APIs
- EPC API and documentation

Once he had re-familiarised everyone with the tasks he then moved on to discussing what they have achieved, what they still have to do and what they have decided to leave out. One of the key outcome of this part of the meeting was a discussion about the 'next best action' task that Andy was very keen on at the start of the sprint. After seeing how the team had progressed with this throughout the week, Andy highlighted this as something they had chosen to leave out of the prototype due to the complexity of the task and the limited time-frames. His vision of providing actionable advice at the first possible step was countered by the team. Edie provided examples and scenarios to support her argument that the customer will want to know what has been checked for trust and reassurance purposes (shown in fragment 6.10).

In Edie's example she uses a form of narrativisation to present an example of potential distrust in the data science by the user. Edie posits that if

Fragment 6.10

E: There is difference between my bill is too high and I think my bill is too high, so if the user thinks that their bill is too high but it's not and you are just checking once, all of this information and then you put it up, no your bill is not too high it's just normal, then you can try to save energy by this and this and this, I don't think that the user will be really satisfied with this answer, because we have different users. But going through the whole process and telling okay, now I will check your tariff, now I will check this data that I have from you and now I'll compare your household with other households and then at the end I will not find anything that is a reason to be higher or something, it's gonna be better to understanding and it will be oh okay so they actually did check and they made some effort so for me.

Extract from video of review meeting

the data analytics do not find something which aligns to the customers beliefs (that they are paying too much) then the customer will not be satisfied. From this assertion she suggests more detailed articulation of the data processing steps will build trust and thereby be more likely to meet customer expectations. This was then supported by Hugo and Craig as they mention the reviewing of 'Live Chat' data for the term 'too high' often related to direct debit amounts of estimated bills and not the actual bill cost. This is real user data that they have used to review and gain a deeper understanding of the reasons that customers may use the phrase 'too high'. Thus supporting the view that customer's expectations may not be met if motivation is not clarified before insight driven advice is provided.

These examples demonstrate how the data-work that Edie, Hugo, Neil and Craig had undertaken gave them a range of scenarios in which to present their arguments. By this point in the project they have gained a deep knowledge of the available data and had worked through many of the journeys collaboratively reasoning about the potential insights that different dataset instances and scenarios could provide to particular customers. The building of this knowledge base through the decision tree supported data-work had given them the knowledge and resources to assess the potential risks of the next best action approach as not always being able to address the customer queries adequately. The issues raised here come back to the core difficulties of data-work in terms of the correct identification of the customer motivation and behaviour from very little interactional information. This difficulty in deciphering human behaviour from IoT data resonates with previous work by Fischer et al. (2017) and Tolmie et al. (2016).

As the meeting continued, the team talked through the mapped journeys to inform Andy of their progress. At this point they were located in the meeting room and therefore they did this without using the diagrams, working from memory explaining the steps as they went. This included reviewing the advice that they had generated from the available data. This exchange allowed Andy to gain a deeper insight into the work that has been completed and planned moving forward. He worked around the table requesting information from the members in the same way. For example, asking Craig about the EPC data and John about the API status. Once they had all discussed the work done during the week, Andy gave them an opportunity to report on what they felt went well and what didn't. Edie reported the general progress as good, said the conversation side took longer than expected. Fragment 6.11 demonstrates how important Craig felt the decision tree mapping had been to the process and how the whole team being involved had been useful (lines 1 - 4). Edie also backed this up by stating it helped with defining data requirements and user interaction (lines 5 - 9) In short then, the decision tree work supported the collaborative work of relational tracing[1] between the different elements of the product (i.e. the data and the user).

This snippet highlights how important the decision tree was to the whole team as a central resource to communicate and coordinate their work. The main things that came out of the general review of the week were that they

[1]relational tracing work foregrounds the relationships between the different sociotechnical elements of the product which makes the infrastructure itself visible. Thus, it can be defined as a form of infrastructural inversion (Bowker, 1994)

Fragment 6.11

C: Doing the decision tree was really something that, I think it was good to do it, but with the whole team. yeah because it was, really something that had to be done and also that, maybe we mustn't put off that part. so yeah

E: Yeah I think it helped for both, not only for defining what kind of data we need and where we can take more data, but also it helped with the journey for the conversation and how the user will interact with the bot. So the decision tree was really really helpful

H: I fully agree with Craig and Edie, because we were a bit scared at the beginning Craig, we were a bit alone [...] trying to build the decision tree and we didn't know what was really useful for you developers. I'm quite impressed by what we've managed to do in a data point of view, but I think it was really the beginning of all our work

A: Yeah I agree actually

(Extract from video of sprint review meeting)

had expectations that were not achievable and that the decision tree was considered an important exercise.

The final part of the meeting involved Edie and Andy giving demos of the conversational work that they had done on the journeys. Mike also gave a demo of some of the work he had been doing on a related project. Mike's demo was done remotely with Andy following Mike's instructions to demo it from his phone. None of the other members demoed their work and this was accepted without question.

The meeting ended with Andy outlining the plan for next week. This was to tie everything together and to have something working with real or fake data. He also informed the team that the following week would be short due to a team away day on the Wednesday and the final meeting had moved to Thursday instead of the Friday to ensure that the PM and key stakeholder could be there. The team left for the day after the meeting concluded.

6.4.10 Detailing the smart thermostat journey

The second sprint began with another kick off meeting. This took a different form to the first meeting. There was less preparation and orientation work. The meeting was fairly short and focused on recapping the review meeting and task planning. This drew on some of the outcomes of the review meeting that the team had held on Friday and set out a plan to move forward for the week. The meeting was attended by Andy (the sprint leader), Neil, Craig, Mike, Edie, Hugo, John and the PM.

As part of the recap of the review meeting Andy reiterated that the 'next best action' task had been postponed and that a decision tree approach was being worked on instead. His justification for this was that it was too complicated to achieve within the tight time-frame. This further demonstrates how only tasks that can be completed within this time frame were included and that more complex tasks were put off to a later date. This was due to the requirement of having to hand something over to the customer for them to 'play with'. It is notable then that this requirement has somewhat restricted and framed the approach to the design work.

Following this update Andy ran through some tasks that he had specified and added to the document off the back of the review meeting on Friday. He ran through these tasks in the meeting to highlight challenges that needed addressing. A particular area of difficulty that the team had highlighted was how to present complex data to customers through a conversational interface (see fragment 6.12).

Fragment 6.12

SL: we talked about presenting the [smart thermostat] data maybe something a bit differently than just conversational
N: yeah
SL: so we need to work on finding a good way to present that, whether it's a [...] more detailed graph or some icons or something, but not just a sentence which could be difficult to actually populate, so we need to find a way to do that.

(Extract from video of week two kick off meeting)

The data analysts had previously highlighted the presentation of data as a key challenge that they were struggling with. Andy had recorded this challenge as an action which needed addressing during the second week of the sprints. He presents this as a potential need for a different approach (lines 1 - 2). He also indicated that at this point they do not know what that different approach may be (line 7). This exchange serves to highlight tensions between the chosen delivery method of a conversational interface and the standard conventions of data presentation. These tensions have been surfaced through the articulation of a challenge presented by the data analysts during an update report to Andy (the sprint leader). The result of this is an additional task allocation to focus directly on the challenge in order to find a resolution.

After the meeting the team went back to their desks to work on their allocated tasks. Edie, Hugo and Neil were tasked with creating the conversation for one of the journeys. Hugo and Neil had been looking at the data that could potentially be included and Edie was trying to convert their ideas into a conversation through the API.AI and Facebook interfaces. As data scientists Hugo and Neil were keen to display the data in the most readable way possible regardless of the UI, whereas Edie was focused on how the UI could deliver what they were asking. This conversation ended up with some experimentation over displaying graphics such as graphs followed by the creation of a very long figure heavy response that none of the team were happy with. At this point the team decided to ask for assistance from the PM. After briefly discussing the issue with the PM, he suggested that they move through to the meeting room and map it out on the whiteboard there.

At the beginning of the meeting the PM clarified the design brief and then asked a number of questions to gain an understanding of where the team had got to and the specific challenge that they were struggling with. This enabled him to reiterate the design brief in the context of their problem.

Thus creating a starting point from which the design work could commence.

Fragment 6.13

PM: at the moment it doesn't feel like we're telling the customer how to save money.
E: no we are not at the moment we are just giving them information and then out of this information based on the data that we get from their thermostat we have to give them advice of how they can improve that.
PM: so, okay, so the things that we need to do now are to work out how to deliver the information in an understandable and customer friendly way.
E: yeah.
PM: and then we need to know what advice we need to generate as a result of the information that we are giving them.

(Extract from video of design meeting)

Firstly he established and reiterated the design objectives (shown in fragment 6.13) of addressing the initial customer query (lines 1 - 2) in an understandable and customer friendly way (line 9) to generate and provide advice (lines 11 - 12). This initial exchange served to orient the team to the design brief before proceeding to assess and resolve the tensions.

Then he went on to gain insight into where the team had got to when mapping out the journey. He did this by asking questions of the team members and using the whiteboard to record the relevant responses. This enabled him to map out the beginning of the journey that the team had been working on and to identify the point at which the problem they were struggling to solve began. The journey the team were working on at this point was initiated by the entry point *'How can I save money?'* From here the user was given 4 options and in this use case, had selected *'Smart Thermostat'* from the options. The user was then presented with an option of whether they would like to see their schedule. From there they received what Edie referred to as *'the long message that we have to convert into something else'*. Once the PM had established this information from the team he had a starting point from which the meeting's design work could commence.

During the meeting the team made a number of important design decisions regarding this chat sequence. These decisions included the order and draft content of the sequence itself alongside decisions about whether to include various data forms and how to best utilise the data-streams available to them.

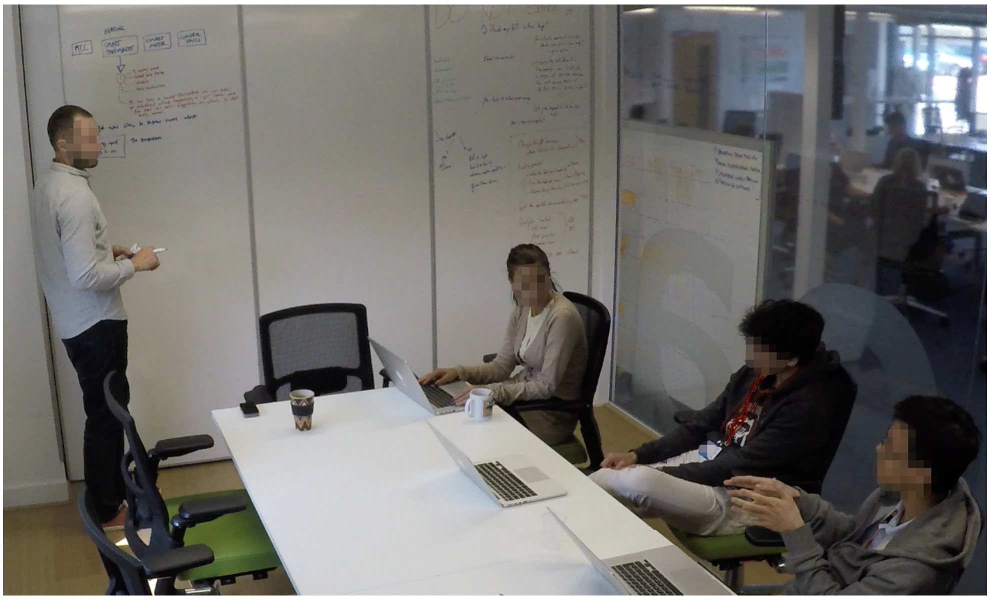

Figure 6.9: Design meeting to address data presentation challenges

It is worth reiterating here that there were 5 data streams available to the team. The two streams from the smart thermostat data was boiler-on-time and set point. They also had the option of using weather data (specifically outdoor temperature), customer account data and energy performance certificate data (EPC).

The first thing that the team focused on was an introductory step suggested by the PM to provide context to the user by explicitly explaining the link between the boiler-on-time data and the money before they provide the on-time information. This suggestion was accepted by the team and was added into the chat sequence. The team then went on to assess the options they would like to offer the user within the chat sequence. The initial and presumably preferred option for the PM was to offer the user a choice of which information they would like to receive. However, Hugo countered this because Boiler-on-time has a different relationship to saving money than the other two. He presented a kind of hierarchy stating boiler-on-time is a *'consequence'* of set point and outdoor temperature. This relationship mapping allowed the team to create a logical sequential order for the conversational interaction to follow.

The discussion then moved on to the next step of the sequence. As demonstrated in fragment 6.14, the PM first describes the data streams of set-point and outdoor temperature as being 'more interesting' than boiler-on-time (lines 1 & 2). His justification for this was that it was actionable for the user (lines 4 - 5). Hugo points out on line 6 that although the other data streams may be more *'interesting'* boiler-on-time needed to be stated. This exchange ties back to the goal of adding value for the customer by providing advice supported by information (or data). The focus was brought back to how the information could be utilised by the user to meet their goal of saving money through the use of a scenario (lines 7 - 9). This served to focus the team on the end of the chat sequence; ensuring that they ultimately provided actionable advice in a customer friendly manner.

Fragment 6.14

PM: So boiler on-time is interesting but the reasons for the boiler being on are more interesting do you think? Do you agree?
H: Yeah yeah yeah
PM: Because that's something you can do something with or not. Even knowing that my boiler was on for 172 hours doesn't really help me. It just states the fact.
H: But you have to state it anyway
PM: Of course, no I agree that, but knowing now. The bit I wanna know, ok fine, but what do I do? that's why I'm here, I wanna save money so what do I do to reduce this? ((taps the boiler on-time step on the whiteboard))

(Extract from video of design meeting)

On the basis of needing to provide these actionable insights, weather data differs from set point data. While it may explain changes in on-time it is not something the customer can control. It is also not always going to be directly related to the customer's bill. This was highlighted by the PM with an example of 'August' as a time of year when it would be irrelevant. As a result of this discussion the team decided not to include the data stream within this sequence.

The presentation of the information was the next challenge addressed by the team. Fragment 6.15 shows the team discussing how to display the boiler on-time data to the customer. They were trying to ensure that the information presented was both meaningful and customer friendly, as per the design brief. Hugo suggested that boiler-on-time could be presented to the customer in days rather than hours (lines 1 & 2), however the PM counters this (lines 3 - 5). The justification offered by the PM is that heating is scheduled in hours, thus suggesting some external consistency, relating to a unit of measurement that the customer may already be used to. Hugo further explains his concern (line 7) by stating the he feels the *'customer will freak out'* at seeing such a large number. The conclusion of this was that they went with hours as the PM had suggested.

Fragment 6.15

H: I think it would be days because if it is for the last 30 days
hours is going to be pretty big.
PM: Yeah, well, but days is kind of a weird thing to compare
boiler on time in, I think, hours. You schedule your heating
in hours rather than days. I don't know I think we just need
to see how that-
H: we can display hours but I feel the customer will freak out.
Because sometimes you know it's uh-
E: massive

(Extract from video of design meeting)

The team went on to discuss how to present the information to the customer as text based presentations were deemed inappropriate for this kind of data insight. After concluding that graphical representations of a leader board would not fit in to the conversational interface well, they decided to present it all within a downloadable PDF document. The exchanges within this meeting demonstrate how the team maintained focus on the design brief of presenting meaningful and actionable advice to customers from data. They used constructions of the user through predicted reactions (such as "freak out" - fragment 6.15) to ensure the human perspective was applied to the data-work and design reasoning.

6.4.11 Finishing off the prototype

From this point the focus of the team was on what needed to be done for the planned Demo to the stakeholder on Thursday. In a stand up meeting at the start of day 7, John advised the team that he was struggling with the API, having problems getting it set up. Referring to the decision tree the project manager discussed which journeys had been completed and which were still *'missing'*. Three journeys were mentioned as being missing, these were; 'my bill is too high', 'smart meter install' and 'smart meter info'. The PM put forward a suggestion that they could remove some of the journeys and give general advice on smart meters on a really simple level, in order to save time.

Following the stand up the PM took more of a hands on role than he had during the rest of the sprint. He spent the day working with different members of the team to make sure their tasks were completed in time for the demo and that any required assistance or decisions were not holding anyone up. He initiated conversations with team members by asking questions about their progress at various points during the day. He had done this during previous days to gain an understanding of what team members were working on, however the focus today involved more project management decisions around what should and shouldn't be focused on before the demo.

The time from here was spent working individually and in pairs. Mike spent time with Craig helping to tie the data-work into the backend. As one of the main developers on the project he helped Craig to get the EPC data stream working and helped Edie to tie in the front end with the database.

The project manager and Hugo worked together on the task of using set point to group customers as discussed in the design meeting. Hugo had been working on gathering and analysing the data and as a result provided the PM with the percentage of customers at each interval on the set point. This was not as expected due to the groupings being skewed. The PM had expected this to be normally distributed which would allow them to group people, however this was not the case. Hugo put forward an alternative suggestion for how they may be able to group the customers using boiler on-time data instead.

Fragment 6.16

H: Sorry I have to make it mathematical (goes to draw on whiteboard) The data looks like that, the mean is here at 200 hours, so it's 8 day over a month so here is where the majority of customers are, so here is 4 day. (draws graph on whiteboard to explain the data).

PM: so it could be that we divide the customer groups this way couldn't it?

H: yeah.

PM: it's not the nicest way of doing it but at least it tells the customer where they fit we have to accept that if we're doing an average it may not be exactly what the customer wants, there might be people who are disabled or unusual cases. For some people it might just be that their dad has the heating on all the time just because he does. So we can use this data?

H: yeah it might be that we can.

PM: well I think this is just a statement really, this is where you fit, you might want to think about doing this.

(Extract from field-notes)

Fragment 6.16 demonstrates the articulation of data-work from Hugo to the project manager. To achieve this Hugo turned to the whiteboard to present visualisations of the data (lines 1 - 2). This further highlights the need for data visualisations as a means of communication and the tensions between this method of communication and the conversational interface they are creating. Through this exchange Hugo presented a back up option to categorising customers by set point data. While the PM does agree to this method of categorisation he has some concerns. He voices these concerns as 'not the nicest way of doing it' (line 9) and 'may not be exactly what the customer wants' (line 11). At the end of the exchange the PM brings it back to the output from the interface as conversational, or ‘just a statement’ (line 17).

Whilst preparing for the demo in the morning of the meeting, the team worked individually on the tasks that they had remaining. John and Craig left the office to work from home and the other members worked at their desks. An hour before the demo meeting commenced John returned to the office and announced to the team *“the API is broken”*. John and Mike then worked together to create mock data before the meeting. This further highlights the importance of having something ready for the customer to look at in the meeting. It may have been possible to explain this to the stakeholders or to postpone the meeting until they had resolved the issue. However, the team decided to fall back to a contingency plan of using mock data for the prototype demo rather than postponing the meeting.

The meeting itself included the wider members of the team as well as two members of the project sponsor’s team (shown in figure 6.10)

Figure 6.10: Stakeholder demo

The meeting consisted of four sections; a demo of the prototype, feedback from the stakeholder, a plan for the next steps and then, a team only evaluation of the product and sprint.

The demo

The team went through a series of journeys on the chatbot showing the pre-planned conversation sequences on a large screen. The demo was initially conducted by Andy until he encountered a problem from being logged in as the wrong type of user. His user did not have a smart thermostat and therefore could not get onto the smart thermostat journey they were looking to demo. At this point Edie plugged her laptop into the screen and continued with the demo as a different user type. The demo went on for 23 minutes with Edie working through the planned journeys and providing a running commentary. It contained very little in the way of questions and feedback from the stakeholders.

The feedback

After the chatbot has been demoed the PM asked the stakeholders whether they had any feedback for the team. Feedback was then offered from the lead stakeholder and other team members who weren't directly involved in the sprint.

The feedback given related mainly to the user interface as opposed to anything relating to the content or the data that was being presented. This included comments like; "wordy" in relation to the length of responses and "[in]consistent" in relation to the type of input offered to users (i.e. buttons or text). The feedback at this point was fairly limited as the prototype had been designed to be taken away and tested so the stakeholders would have time to present more detailed feedback at a later date. A discussion around the expectations and technical aspects of the user testing followed the feedback before the stakeholders and the wider team left the meeting. The meeting concluded after the team had discussed the final tasks that needed to be done before the handover of the prototype.

On the final day of the sprint the team worked individually to complete these tasks. They included; setting up user profiles on Facebook, ensuring that data-streams were either working or mocked up fully and tidying up the journeys so that there were no loose or dead ends. As members finished their allocated tasks they marked them as completed on the backlog. Once a member had completed all their allocated tasks they were able to leave the sprint. This involved either leaving the office for the day or moving onto other projects.

6.4.12 Post sprint

It is worth noting, in the case of this project the chatbot itself was not taken to market for numerous business reasons including the ongoing management overhead: it was left dormant after incorporation of a recommender database and two rounds of internal user testing. Instead, work done and insights gained from it were subsequently fed into other related projects throughout the business.

6.5 Chapter summary

This chapter has demonstrated; 1) relational tensions between the goals and conventions of communicating data-science and the user experience delivered through a conversational user interface; 2) the use of decision trees as a method of visualisation of infrastructural layers to situate of data-work and design reasoning; 3)the complexities of designing with multiple complimentary data streams from deployed third party devices alongside internal customer data and external open data to provide data-driven insights and advice. As such, it builds on the long-term challenges of supply chain risks in IoT design, highlighted in chapter 4 (section 4.5.2.2). It also helps to begin addressing an identified literature gap in understanding the "nuances of using data within NPD" (Lee et al., 2022, p12). Here a diagrammatic approach to gaining visibility over infrastructural states and relational tensions is demonstrated. This further builds on the infrastructuring methods uncovered and discussed in Chapter 5.

In a similar way to the notions of elemental state used by the WISP team in study II, the LEC team also drew on notions of elemental state. However, in this case both the notion of insightfulness and that of meaningfulness were based on stakeholder goals and values. Within the work of exploration of the data and the anticipated user goals of saving money and energy the LEC team developed core notions of elemental states central to the design problem (similar to that seen in study II). In this case these explorations are linked directly to the design brief of providing personalised advice to customers from a variety of data, this is in contrast to the surfacing method seen in study II where the design brief was worked up systematically as a direct result of a breakdown. As with study II a key design challenge that is brought to light here is that of gaining visibility over invisible elements of the sociotechnical infrastructures that comprise the system as a whole in order to support design reasoning.

By way of supporting this design reasoning and the LEC team relied on decision trees as a central resource of the data-work involved in prototyping this advice giving chatbot. The team used the tree structure to make the available data accountable to all members as they collaboratively designed conversational energy related advice to assist customers with their energy queries. Challenges were seen in relation to understanding the specific motivation of the customer with mitigation steps put in place to ensure that the data insights provided to the customer were relevant and actionable. The decision trees were used to pull together and visualise formalised user motivations in the form entry points through a user journey of interactions between the customer, data and interface resulting in actionable energy related advice. Collaborative design reasoning in relation to available data streams and the generation of insights for specific customers was situated using these diagrammatic representations.

6.6 Study III conclusions

Using a form of diagrammatic representation to work up the design of a chatbot allowed the team to incorporate a form of sketching Schon (1983); Cross (1999) into their work, using the diagrams as an abstraction method to work through manipulation of data streams and anticipating customer reactions. Using branching structures to represent these steps as sequential events early in the design process can be beneficial for these purposes. However, as design progresses it can become difficult to manage and map relationships between different branches. This raises the question; at what point does sketching and abstraction for design purposes become the underlying architecture of the chatbot itself? There is a lack of focus on this element of chatbot design both in academic literature and industry documentation Castle-Green et al. (2020). In addition, the use of a branched structure can potentially restrict a user once they have begun to progress down a particular branch, thus almost leading or funnelling users after a certain point. This is particularly true in this case where a chatbot interface is being crafted to disseminate findings from IoT data work. Additional design challenges are therefore encountered as a direct result of the method used to gain and maintain visibility over the sociotechnical infrastructure. In particular, 1) services incorporating large numbers of data streams will become unwieldy to work with and as a result expensive for businesses to resource. 2) user experiences are restricted to those that have been scripted resulting in low flexibility of use. The lack of progression of this project raises questions over the appropriateness of the methods used, indicating that care should be taken to avoid falling into a demo trap Grudin and Jacques (2019), where the design of prototypes is focused on demoability rather than commercial viability of a finished product. In this way the sprint methodology may also be questioned in its appropriateness as a method that places tight time-frames on visible deliverables. This is particularly relevant with IoT products as sociotechnical infrastructures where the very nature of their ubiquitousness and infrastructural nature potentially conflicts with business approval processes.

Chapter 7

Discussion

7.1 Chapter overview

This discussion chapter pulls together the findings presented in the study chapters (4,5 and 6) and situates the contributions within the context of related literature. Through this reflection, core design challenges relating to infrastructuring (Karasti, 2014; Karasti et al., 2018), data-work (Fischer et al., 2017) and digital plumbing (Tolmie et al., 2010) are presented, grounded and expanded upon. Areas in which theory practice gaps still remain are also identified and presented as calls for further research to support practitioners within the commercial field of the IoT. This chapter first presents three areas in which tensions between infrastructural elements have been identified. Following this practitioners methods of maintaining visibility over these tensions for the purpose of framing, situating and supporting design reasoning are discussed. Finally, the work of the digital plumber is discussed within the context of the findings of study II. The chapter concludes with a summary of contributions and discussions on implications and limitations of this research.

7.2 Introduction

The research questions proposed at the start of this thesis are focused on gaining insight into the work of IoT related design within commercial settings. Specifically looking at:

RQ1 How commercial IoT related design teams organise their work?

This overall aim was achieved through consideration of the secondary questions:

RQ2 What design challenges are being faced when designing IoT related products and services within a commercial context?

RQ3 What design practices are being applied to IoT related product and service design within these settings?

RQ2 was initially addressed through an interview study reported in chapter 4 which presents a number of challenges relating to embeddedness, the long-term nature of IoT and business related constraints. Through this exploratory study, along with the literature review in chapter 2, the long-term service nature of the IoT was identified as an area with prominent design challenges but where research is lacking. This then became a key direction for this thesis to follow. As demonstrated in chapters 1 and 2 much of the academic research in the ubicomp and HCI literature has focused on the initial design of products and the challenges faced by designing and deploying sensing systems (Lee et al., 2019b). A research through design approach is common (Zimmerman et al., 2007) as is user research within people's homes (Tolmie et al., 2010; Fischer et al., 2017; Tolmie et al., 2016). The practice-based studies, reported in this thesis, directly address a call to move beyond the lab and gain a focussed view of the longer-term sociotechnical infrastructural challenges within the IoT (Fox et al., 2006, 2018; Odom et al., 2016). As such, RQ3 was addressed through 2 case studies looking at design practices used during the modification of a deployed alarm system (study II) and the use of IoT data streams to provide a secondary service of data-driven energy advice to customers (study III). Infrastructuring research has touched on the long-term sociotechnical complexities of deployed systems. However, these studies have focussed on the wider perspectives of infrastructuring often considering the social and political engagement aspects of large scale public infrastructures (such as, civic engagement (Korn and Voida, 2015), healthcare systems (Simonsen et al., 2020) and community networks (Crabu and Magaudda, 2018). This thesis helps to fill this research gap by taking a more focused view of IoT system design than previous works, unpacking design work as it happens within a practitioner context.

The following sections discuss design challenges and practices uncovered through the empirical investigations reported in this thesis. A key theme that emerged through all three studies was the challenge of addressing relational tensions between differing perspectives (or object universes Bucciarelli (1988); Neumann and Star (1996)) within the design context. The following sections discuss these sociotechnical challenges in more detail.

7.3 Identification and management of relational tensions

In their discussion of sociotechnical information infrastructures (Star and Ruhleder, 1994, 1996) highlight the relational nature and levels of complexity involved in infrastructural work. Through this, Neumann and Star (1996) present a view of information infrastructures that looks beyond the object view to consider the relationship of infrastructural elements to people and activities. They drew on Bucciarelli's notion of object worlds as a central concept impacting participatory design, with a focus on bringing together object worlds as object universes. Within his influential works Bucciarelli (1988) suggested, particularly within organisational design settings, participants often come from very different 'object worlds', which incorporate the knowledge, tools, processes and cultures associated with their disciplines, departments and job roles. He argued that design participants coming from different object worlds approach and see the design differently. As demonstrated throughout the studies in this thesis, relational tensions between different goals, values and conventions (or object universes) that make up the sociotechnical layers of IoT infrastructures can arise as a design challenge that needs to be navigated.

7.3.1 Tensions between hardware and software approaches to new product development

The interview study reported in chapter 4 highlights relational tensions in a number of areas, notably within the supply chain but also within the design team itself. For example, Participant 9 (in section 4.4.7.3) described a tension between the hardware team, who's job it is to create a product with a level of permanence that can stand the test of time when it has been deployed, and the software approach of minimum viable product launches and continual updates to the live system. These processes are comprised of very different operational models (Lee et al., 2019b). However, Participant 9 was keen to ensure that regardless of these tensions, a seamless experience could be achieved for the user. Participant 7 (in section 4.4.6.3) describes the move to IoT as a new approach to product design and a change from looking for perfection in a physical product to creating an experience for a user due to the addition of software elements. Opportunities to learn from use and amend the experience through software changes were highlighted. A point also supported by Participant 11 (in section 4.4.7.3) in his descriptions of changing user experiences remotely. It has been argued that the value created in the development of the product is now within the software and data layers (Lee et al., 2019b) rather than with the hardware elements, although the extent of this shift clearly depends on the product purpose and functionality.

While this particular challenge has been mostly considered as tensions during the initial, it is worth also noting modification here as an area as these tensions can arise again within modification work, this is an area that has not been covered in previous works (Lee et al., 2019b). For example, within study II of this thesis, hardware changes were not explored as an option in resolving the installation troubles experienced by the WISP engineers. As such, the device form and physical functions were treated as an installed base within the design process (Star and Bowker, 2006). During the implementation of the design changes these tensions between the permanence of hardware and flexibility of software became apparent when the team realised one of the devices within the wider system did not have RFID functionality. As a result, a software based workaround of siloed code was used rather than any hardware redesign options to ensure the automated process of channel searching could still be used.

7.3.2 Tensions between operations and technical perspectives when modifying a deployed IoT service system

This section discusses the relational tracing activities identified in Study II (Chapter 5) as the team worked through the identification and exploration of the trouble, of inconsistent wait times encountered when installing alarm systems, that had been brought to the table by Tom, the digital plumbing representative. The systematic sharing of reports and accounts used to give purchase to relational tracing activities, gave the team a foundation from which to surface tensions and collectively work towards a resolution. Within this study the occasioning of the task was the result of an infrastructural breakdown situation which led the team to collectively formulate a workable solution. This infrastructural breakdown, provided purchase for a search process similar to that described by Pipek and Wulf (2009). Secondly they draw on the local knowledge sharing by key stakeholders and systematic tracing of experienced and expected behaviour to foreground hidden mechanisms and foundational elements of the infrastructure (Star, 1999).

The reported findings demonstrate that the smaller field trial management team initially lacked the knowledge and visibility over the software processes to explain breakdowns in connectivity between alarm devices and supporting infrastructure. Therefore other key stakeholders were required as part of an exploration process in order for a resolution to be found. Incorporating key stakeholders in a search for breakdown accountability through knowledge sharing that foregrounds hidden elements and facilitates relational tracing, can be conceptualised as a form of infrastructural inversion (Bowker, 1994; Star and Ruhleder, 1996; Simonsen et al., 2020). In this way, the project team in the study described in chapter 5, purposely and systematically foreground aspects of a sociotechnical system which are routine to them but remain invisible to others.

Pipek and Wulf (2009) refer to meetings between design experts and practice experts as an important infrastructuring activity for supporting new usage innovation. Simonsen et al. (2020) also reported on meetings between super-users, working with a participatory design effects-specification approach, as an environment in which infrastructuring activities occurred. Based on the findings in this thesis the importance of meetings between experts to facilitate local knowledge sharing as an activity to foreground related invisible elements of the product-service infrastructure and surface relational tensions is also demonstrated, both within study II and study III. In the case of the alarm system modification described in chapter 5 (study II), this was a meeting between the operational and technical experts: representatives of the two core perspectives that were present and in tension at the point of breakdown. Neither of these parties were design experts, however, each was an expert in their own domain, namely that of the underlying software, technology capabilities and field engineer work processes. While the digital plumbers at WISP could be considered as a type of super-user, the task itself was derived from a breakdown situation and was *not* facilitated by the researcher, as it was in the research by Simonsen et al. (2020). This thesis therefore builds on current knowledge by offering a different perspective in relation to how infrastructuring work of gaining visibility over infrastructural elements can be occasioned and self-organised by practitioners within a setting. The particular breakdown in this instance was troublesome for the digital plumbers working on installs as it did not fit their understanding of how the system should behave in that context. Something which Orr (1996) noted as, a situation that both holds the interest of technicians and makes them feel uncomfortable. Therefore this lack of visibility over the connection wait times was something that caused tension and so needed to be explored and resolved.

Visibility over tensions within the WISP team's exploration process was achieved in a number of ways, as the team worked together to systematically foreground the relevant information to their area of experience and expertise. Firstly **accounts of experienced behaviour** are seen, these are presented primarily by Tom as part of his role as Technical Operations Manager (over-seeing the digital plumbing team). Tom presented accounts of installations through descriptions of the steps taken by the engineer and the behaviour experienced from the device. The behaviour is reported by Tom as 'bothersome' and something which did not fit with the technicians' understanding of how things 'should be'. While it does not compromise the performance of the system as such, it is unexpected. As Orr (1996) notes, it is these situations of unexplained and unexpected behaviour that often prompt technicians to share details with their team, thereby occasioning collaborative troubleshooting work. It is also worth noting here that, as a boundary object (Star, 1999) the internal monitoring system played a key role within this account sharing work. Tom used it initially to gain further visibility during the breakdown regarding the status of the device. It was also used to give further context to his accounts during the meeting through interaction and error logs stored within this cloud system. Finally, it was used by Luke (the Test and Verification Engineer) to observe the hidden behaviour of 'wandering' around the channels. This additional information was used to link the 'join' and 'rejoin' processes allowing the team to assess and address a seemingly related problem. The internal monitoring system, in this respect, serves to provide a glimpse of these relational aspects, although, much of the technical and operational work involved in the development and management of a solution of this nature remains invisible to the different perspectives. Hence the need to support it with focused knowledge sharing processes to further explore relational tensions between different object worlds (Bucciarelli, 1988) when breakdowns occur.

The second way in which the team systematically foreground situated knowledge is through **reports of expected behaviour**. Dean as the software developer with the relevant knowledge and expertise responded to Tom's accounts with an explanation of the context that would cause this observed behaviour and the way in which the device is programmed to respond to this context. Dean's explanations are thus produced to elaborate upon, and contextualise—and in doing so create a relation to Tom's reports. The final stage of this process was for Tom to present information about the practical time challenges of the on-site engineer, highlighting the tensions between the device behaviour and how that device behaviour relates in situ to actual engineer practices.

The findings presented here demonstrate the ways in which the team traced **relations between experienced and expected behaviour** to find the underlying cause of the breakdown as a specific scenario of connection difficulty. The result of this **systematic exploration work** was the surfacing of tensions between the goals of the engineer and that of 'the device'. As the device itself struggles to connect to an unknown channel the engineer must wait, something which is incongruous with the efficiency goals of the engineer. Partly from an operational perspective in terms of business time costs, but also potentially as something that could impact the engineer customer relations if viewed as a lack of knowledge or skill (Orr, 1996). Furthermore, the 'knowledge' which the device is searching for is already known (or at least easily accessible) to the engineer. The tension is there because the engineer is on-site at the time, waiting around, which is something that was not the case with the 'rejoin' process. This process of identifying tensions thus generated a new focus, understanding and basis for the team to move forwards with the detailed design work. In summary, the process of knowledge sharing, as seen here, serves to define the **notions of on-siteness and connectedness as infrastructural elements in tension** with each other. This is somewhat similar to the defining work of fasting times described by Simonsen et al. (2020) as an early step in the design process. In this case, however, this is a much less formal process surfaced through behavioural accounts and resulting in a broad framing for the subsequent 'fleshing out' work by foregrounding these two core elements.

7.3.3 Tensions between conventions of data-work and user experience through a conversational user interface

Within study III (chapter 6), relational tensions were surfaced between the conventions of communicating data through visualisation (Steele and Iliinsky, 2010; McCosker and Wilken, 2014; Fischer et al., 2016) and the conventions of conversational interface design as through voice, text or button based interactions (Reeves et al., 2018; Fischer et al., 2019; Haugeland et al., 2022; Shevat, 2017; Moore and Arar, 2018). These tensions were foregrounded as the team systematically undertook data-work (Fischer et al., 2017) through a process of creating prototype ‘chat sequences’ to add value to various data streams. In their attempts to convert smart thermostat data into actionable energy saving advice, the data analysts articulated (Schmidt and Bannon, 1992) potential insights to the rest of the team using data visualisations (such as graphs depicting different usage levels between households) drawn on a whiteboard (see fragment 6.16). These insights were then matched up against the design brief of generating meaningful advice and verified through the use of predicted normative reactions of users (see fragment 6.15). While a number of tensions were raised and worked through by the team, the insurmountable tension between the conventions of communicating data-work as visualisations and those of conversational interfaces came to the fore when some of the more complex data-work was translated into text based conversation (see fragments 6.12 and 6.13). For example, when comparing current bill and usage information from similar households and previous bills, the outcome was a ‘wordy’ response from the chatbot that none of the project team felt was an acceptable user experience. Attempts were made to rectify this through the addition of conversational steps to no avail, before the team decided to depart from the conversational interface conventions through provision of visualisations of the data via a PDF report. This resonates with findings from Fischer et al. (2014) who found during a design workshop with energy advisors, the use of data visualisation were seen as effective tools to support communication of energy related data to clients. The resolution in LEC’s case was far from ideal but was considered their only option given the project constraints. This is an example of what Star and Ruhleder (1996) refers to as challenges of working with an installed base. As the team tussled with and reasoned about the data to find ways of providing advice, the differing conventions became visible as a sociotechnical infrastructural elements in tension; a design challenge that needed to be navigated.

Previous descriptions of data-work within the energy advice domain have described it as a collaborative endeavour, with control and visibility over the full IoT system from which to make data capture accountable, support the situating of sensors, capture contextual metadata, make sense of the data and then turn it into action (Fischer et al., 2017). Within the context of the study described in chapter 6 of this thesis, much of this collaboration is either not possible due to a lack of physical presence or is presumed to be distributed and therefore outside of the control and visibility of the data-work occurring within the design team. As the data insights here were being generated from third party data streams there was very little contextual information or control over placement of sensors (e.g. digital plumbing). Additionally, the process of turning the data insights into action was invisible to the team and was only made visible as hypothetical reactions of users receiving data insights from a chatbot as they move through the journeys the team had mapped out. In this way, members were anticipating tensions between the data insights and the meaningfulness of these to the customer.

The team constructed a sequential order to the data used to drive the step by step elements of the design. This approach sees the systematic tracing of relations between the data insights and the design brief as they draw on their knowledge of data streams alongside an exploration of potential user reactions. Through this process additional tensions were identified in relation to the number of steps in which to deliver the information to the customer. For example, trust was cited as a reason not to opt for the ‘next best action approach’ of delivering advice efficiently in one step, as the team would not be advising the user what data had been checked and how (see fragment 6.10). This was a particularly compelling argument in the scenario of data insights that do not match the customer’s goals and expectations. Here, the team had to **anticipate potential scenarios** and perform a process of design reasoning about **how users may react** to the delivery of insights from **potential dataset instances** and then adapt the dissemination of the insights and advice accordingly, so as to reduce any potential tensions (e.g. negative reactions). An example of this was to put additional steps into the conversational design to build trust with the user through demonstrations of data checks adding context to the chatbot responses (see fragment 6.14). Thus tying into design conventions of making topic-led interactions more engaging (Shevat, 2017), but going against the design objective of providing the 'next best action' in one step.

7.3.4 Section summary

This section has discussed a number of tensions arising between different object universes (Neumann and Star, 1996) within the IoT design process. This is not surprising in that the multifaceted, layered nature of IoT systems requires collaboration between disciplines from very different backgrounds, (such as software, hardware and data) and adaption of delivery methods to achieve a holistic user experience. As noted by Leiva et al. (2019) in their work investigating tensions between designers and developers within the interactive software field, these tensions can have a significant impact on the design work. In particular they suggested that incongruity between "processes, tools, and representations" of these differing perspectives can increase the need for "unnecessary rework". From this they were able to create a framework and digital collaboration tool to assist with the specific areas of design work that were impacted. It is therefore important that the tensions identified here as significant within IoT design work are further researched to investigate whether negative impacts exist here. In contrast to the work of Leiva et al. (2019) the tensions identified in chapters 5 and 6 were not reported as detrimental to the team's internal communication. Here they are demonstrated as potentially useful to the design team going forward in that, once identified by the team, they can be used as a resource to frame, steer and situate the design decisions moving forwards.

7.4 Maintaining visibility over and addressing relational tensions

Once tensions have been identified within the design process, it is important for design teams to find a way to maintain visibility over the tensions in order to incorporate them into their collaborative design reasoning. This is important both from the perspective of ensuring the right object universes are represented at ‘the table’ (Bucciarelli, 1988; Neumann and Star, 1996) but also as a way to situate the tension and related design reasoning within the different elemental layers of the product-service itself. Applying an infrastructuring lens to studies II and III, this was achieved through notions of elemental states, drawn upon as a resource for the team to situate their reasoning. Within study II (chapter 5) these were the notions of ‘connectedness’ and ‘onsiteness’ that were surfaced as in tension during the ‘exploring the trouble’ phase of the meeting. In study III (chapter 6) these were the notions of ‘insightfulness’ and ‘meaningfulness’ that represented the teams constructions of possible dataset instances and predicted normative reactions of the user. These will be discussed in more detail in the following sections.

7.4.1 Notions of connectedness and on-siteness as resources for design

Within the work of exploring the reported trouble, the WISP team (chapter 5) developed core notions of elemental states central to the design problem. Based on the collective knowledge that the shared goals and values were ‘establishing a connection’ and ‘efficiency of the operational elements’ (i.e. time engineer is required on-site), the team developed notions of connectedness and on-siteness. These were then drawn on as resources for design, providing a framework for the team to anticipate and assess potential impacts as they **traced relations** to flesh out the solution. These notions are situated within the network layer and digital plumbing layers of the deployed IoT system. By drawing on opportunities and limitations of these installed bases (Star and Bowker, 2006) these notions of elemental state were used to support design reasoning through continual foregrounding. Thereby providing visibility over the tensions identified during the exploration of the installation troubles. Each of these notions is described in more detail in the following sections.

7.4.1.1 Connectedness as a representation of networked state

Connectedness in this case, was used by the team as a notion with 4 states; 1) not yet connected, 2) reliably connected, 3) unreliably connected, 4) attempting to connect. Within the 'exploring the trouble' stage of the meeting the tensions raised as the cause of breakdown were in relation to the device attempting to connect. As the team worked up the finer details of the solution they considered specific use cases and drew on the notion of connectedness to consider questions or suggestions. For example, Tom questioned the feasibility of using an RFID tag during installation by stating 'we may not have that connection' and relating it to similar functionality (i.e. the cleaner's RFID tags), a concern which Dean dismissed as the owner's tags are processed locally meaning a connection is not required (see fragment 5.6). In this way Tom used the notion of connectedness to further explore the feasibility of the solution by tracing it through similar functionality and comparing the connection state of the two examples. A further example of this can be seen in fragment 5.7, where Dean suggested the connection is reliable at the point the wake-up channel needs configuring. In this example relational tracing was used to consider similar functionality as the team tried to anticipate and prevent similar breakdowns. The final example is in fragment 5.8 as John suggested the connection may be problematic and therefore not reliable if a whole site channel change is required. Again the connection state of the device was used to anticipate and evaluate the feasibility of suggested functionality changes. These notions of connectedness were used in this way throughout the design process as a resource for design reasoning to allow the team to evaluate the conditions and potential impact of the installed base.

7.4.1.2 On-siteness as a representation of operational priority

While the notion of connectedness can be thought of as physical in nature, the notion of on-siteness is more complex. It has 3 states (1)on-site installation and maintenance, 2) off-site maintenance and 3) no engineer required), which are not as clearly defined as the notions of connectedness. They incorporate goals and values, for example, a state of engineer already on-site alludes to requirements of minimising time, utilising knowledge, having the correct tools. The state off-site is less restricted by time but is reliant on visibility and control through the cloud based product and/or monitoring systems. While the on-site state is used as a resource for design reasoning in the same way as 'off-site' and 'no engineer required', it is the primary state in relation to the breakdown and design change being discussed here. For that reason it also serves to maintain focus on ensuring adequate support for the 'digital plumber' is achieved within the troubleshooting and design session. With the initial breakdown occurring whilst an engineer was on-site, Tom explicitly provided additional information relating to this state within his accounts. The states of off-site and no engineer required are more aligned to general business goals and values shared as part of membership in the project team. In this way, it is quite different to the state of connectedness as it is directly linked to stakeholder values.

With its roots deep in business goals and values, **on-siteness often overrides connectedness** in its weighting for design reasoning. For example, fragment 5.8 shows Tom suggesting that if a site wide channel change is needed he would like to be able to do it remotely without an engineer having to visit each node. John points out that this may be problematic as the channel is likely to be being changed due to unreliability. While it is acknowledged that the connection state is 'unreliable' the goal of the 'no engineer required' state is considered something worth attempting. While they may mitigate this risk by having an engineer nearby and making the customer aware when the change is made, it is still deemed beneficial to attempt it remotely. Another interesting example of the notion of on-siteness being used by the team was in fragment 5.7, where Dean suggested that the wake-up channel configuration could be done either automatically, without the need for an engineer, or manually 'off-site' via the cloud system, thereby reducing the need for an engineer visit. This suggestion was subsequently dismissed by Simon the R&D manager based on the premise that an engineer would already be on-site as it is configured during the installation process. Once an engineer is on-site they will have limited time to wait for an automated process, particularly when they have the tools and knowledge already in place to set it manually at the same time as the operational channel. Here, the notions of connectedness and on-siteness were used together by the team to anticipate potential tensions as a result of design changes.

7.4.2 Notions of insightefulness of data and meaningfulness of advice as resources for design

In a similar way to the notions of elemental state used by the WISP team in study II, the LEC team also drew on notions of elemental state (chapter 6). However, in this case both the notion of insightfulness and that of meaningfulness were based on stakeholder goals and values. Within the work of exploration of the data and the anticipated user goals of saving money and energy the LEC team developed core notions of elemental states central to the design problem (similar to that seen in study II). In this case these explorations are linked directly to the design brief of providing personalised advice to customers from a variety of data, this is in contrast to the surfacing method seen in study II where the design brief was worked up systematically as a direct result of a breakdown. The LEC team developed notions of insightfulness and meaningfulness. In a similar way to the infrastructuring work seen within the WISP case study, these were then drawn on as resources for design, providing a framework for the team to anticipate and assess potential impacts as they **traced relations** between the available data and the presumed customer motivation. These notions are situated within the data layer and user action layers of the sociotechnical IoT system. Throughout the design reasoning process the team created decision trees to situate the opportunities they had identified through their data-work within constructed conversations with an imagined customer. This allowed them to continually **trace relations** and **visualise tensions** between the outputs of data-work and the user experience generated through a conversational user interface, to ensure they were able to provide meaningful tailored advice. Each of these notions is described in more detail in the following sections.

7.4.2.1 Insightfulness as a representation of dataset instances

Insightfulness in this case, refers to a representation of dataset instances with 3 states; 1) indicators of specific behaviours, 2) interesting insights and 3) questionable validity. These dataset instances were created by the team through a process of data-work. There were 4 different types of data-work observed during the course of the 2 week sprint process. These included; collaborative ideation of potential insights (such as, that seen in the kick off meeting), preparation of data streams (such as, setting up APIs), formal analysis performed by the data analysts (such as, correlations between different data streams) and communication of data insights (both within the team and as crafted conversational steps within the chatbot design). Within their paper Fischer et al. (2016) unpack the ‘machinery of interaction' (Sacks, 1984) of data-work related to energy advisors who were using sensor data to provide face to face energy advice. In their case the data-work is organised into 3 procedure types, these are anticipating the data, rehearsing the data and performing data-work. Within the data-work performed by the LEC team there is also an element of anticipating the data through ideation and preparation work. There is rehearsal work in the way the team communicate insights to the rest of the team as a form of validation. However, the performing of data-work described in this thesis differs in that it is distributed and delivered through a chatbot in a pre-prepared format. For this reason the team must undertake additional preparation and anticipation work to evaluate the potential insightfulness of the data for the user. As the team worked through the details of the data-work they drew on customer typifications as a way to frame their design; for example, customers with smart thermostats and customers without smart thermostats. From this alongside the decision tree mapping the team were able to consider specific use cases of dataset instances and drew on the notion of insightfulness to reason about how the available data could be used to provide advice.

The three states; indicators of specific behaviours, interesting insights and questionable validity were continually assessed throughout the collaborative design work. A good example of how the team considered 'indicators of specific behaviour' can be seen in fragment 6.5. In this the team identified a specific user behaviour through the use of a hypothesis that users may misunderstand the way a set point works. Hugo then corroborated the theory by finding a correlation between outdoor temperature and changes in set point from their data sample. Thus, they identified an indicator of the specific user behaviour of turning up their thermostat set point when the outdoor temperature drops. This was then confirmed as a behaviour that would cause an increase in bill cost and therefore something they could address through information and advice. This insight was noted by the Project manager as particularly interesting due to it being "behavioural data" in fragment 6.9.

Fragment 6.14 provides another exemplar of how data was labeled as "interesting" based on the insights it provided. In this case boiler on-time was "interesting" because it provided background factual context for the user but the reasons for the boiler being on were "more interesting" as it was considered as a potential basis for actionable advice. The state of questionable validity arose when the team were lacking data or context. A good example of this is shown in fragment 6.6, where the team are suggesting that they may be able to identify bad habits through comparisons of usage across households to check for a big difference that might provide some insights into whether the customer is actually paying too much, or if "they just think they are". The PM pointed out that while they might know what the house looks like they don't know how many people live in it, thereby questioning the validity of any insights due to a lack of contextual data. This resonates with comments from Fischer et al. (2014) and Dillahunt and Mankoff (2014) in reference to a paucity of information about household consumption limiting the advice tailoring abilities of advisors and the importance of social contexts for validity of insights from comparisons.

These notions of 'insightfulness' were drawn upon by the LEC project team throughout the data-work as a resource for design reasoning. This supported the team in the evaluation of the potential impact of data analytics and communication of various (real or hypothetical) dataset instances.

7.4.2.2 Meaningfulness as a measure of advice

Meaningfulness in this case, refers to the way in which the team assessed their intended outputs against projections of the user. As such, this was a notion of elemental state relating to the user action layer of the sociotechnical IoT system with 3 associated states; 1) actionable advice, 2) general information and 3) outputs that do not meet user expectation. In order to apply these notions to their design reasoning, the team worked closely with the design brief of providing advice along with constructions of various users.

As seen in the work of Martin (2012) and Sharrock and Anderson (1994) designers often draw on their knowledge and experience to produce and use representations of the user to support arguments and assist with decision making. This was observed within the LEC case study reported as study III (chapter 6), where members can be seen to construct the 'shape' of end users through the use of narratives to present and justify ideas or arguments to the rest of the team. LEC's prototyping team worked to construct the 'end user' throughout the design process. This was achieved in a structured manner through ideation sessions and customer typifications. It also included informal presentations of scenarios and presumed normative end user actions (e.g., reactions), ingrained in the reflective design work.

The initial structured approach gave the team a platform from which to draw on their knowledge and experience to orient themselves towards addressing user motivation and goals through the assessment of the meaningfulness, to the user, of the outputs provided. Typification of end user groups was used, in conjunction with logic mapping of chat sequences, to ensure that all eventualities of user types were addressed for each identified entry point. A focus on endpoints of chat sequences, as seen in fragment 6.13, demonstrates how the LEC team's core aim was to provide actionable advice to meet customer expectation. Where that was not possible due to questionable validity of insights (for example, due to lack of contextual data) the aim was to provide relevant general advice. For example, information that may improve a particular user's general knowledge about how to save energy. This notion of meaningfulness can be seen to override the notion of 'insightfulness' particularly where it is deemed that insights do not meet customer expectation, either through debates of customer motivation (as seen in fragment 6.10) or through assumptions of the customer being incorrect (as seen in fragment 6.3).

7.4.2.3 section summary

These notions of elemental state uncovered within WISP and LEC's infrastructuring work, builds on previous research in this area, providing further insights into the ways in which background elements of infrastructures can be constructed, made visible and drawn upon as a resource to guide and support design work as it happens. In particular these notions bear some resemblance to the way in which Simonsen et al. (2020) describe *"characterizations, categorisations and considerations of infrastructural relevance and consequence"*. As such, these notions of elemental state further illustrate infrastructural inversion (Bowker, 1994) used in a generative way to support design. In WISP's case this was driven from the troubleshooting activities of **reporting experienced and expected behaviours in tension at the point of breakdown** that initially bring these notions to the fore, as opposed to the intentional design work described by Simonsen et al. (2020). In LEC's case this was generated through relational tracing between data-work, the design brief and constructions of the user through a process of design reasoning alongside decision tree formation. In this way, this thesis builds on previous descriptions of infrastructural inversion (Bowker, 1994; Simonsen et al., 2020) through the identification and demonstration of the use of **notions of elemental states** to provide purchase to stakeholders as they collaboratively move through design reasoning work towards an acceptable solution.

This approach to infrastructuring served to provide the design teams a framework with which to remain focused on the problem they were attempting to address, while at the same time tracing relations between elements in a way that enabled prediction of potential future interactional breakdowns as a result of their planned design. For the LEC team their focus remained on the design brief of providing meaningful and actionable advice to energy customers. For the WISP team their focus remained on resolving the installation troubles faced by the onsite engineers. By building on these previous examples of infrastructural inversion, a contribution is made here in uncovering *how* practitioners can use this to gain purchase from tensions within the installed base and navigate the key challenge of invisible-in-use but visible-for-design, noted as central in both infrastructuring (Star and Ruhleder, 1996) and ubiquitous computing (Tolmie et al., 2002) literature. Questions are also raised about how notions of elemental state may be generated and leveraged in intentional ways to uncover and work with relational tensions as part of a structured design process tailored specifically to suit the unique design space of the IoT.

7.4.3 Decision trees as a method of maintaining visibility over product service infrastructures

A notable resources used by the LEC team (in study III) to support data-work through the provision of infrastructural visibility, was that of decision tree diagrams. Decision trees have a long and complex intellectual lineage (Loh, 2014). They feature in various statistics-related fields of work (Morgan and Sonquist, 1963) as well as operations research, often used to show conditional variation when modelling in decision making (Magee, 1964). Their adoption as a routine tool for chatbots and commoditised dialogue systems (e.g., DialogFlow, Watson Assistant) has brought them into the hands of a wide range of designers. Although it should be noted that these diagrams are also sometimes referred to as flow diagrams, stories (Shevat, 2017) or conversational paths (Kocielnik et al., 2018) within the chatbot design context. LEC's R&D team also reached for decision trees as a way of designing the flow of interaction with imagined end users, which provided an opportunity to unpack, how designers *actually* use decision trees as a practical tool within their work process.

Decision trees served the LEC team in a range of ways. (1) They acted as a means of ***situating reflective decision making***. In some cases this was explicit with members referring to specific steps to situate arguments or through members relocating to the diagrams on the whiteboard when discussing opportunities or raising questions during the development phase. This was especially prevalent where the team members looked to run something past the PM. (2) An arguably more integral way in which the diagrams served to provide infrastructural visibility and situate decision making within the context of the wider design was seen in the team's systematic approach to the original creation of the decision trees. In that ***the decision tree structure itself anticipated and shaped the process of work***, as the team members began at the initiating statement or entry point and worked through each possible branch discussing opportunities to add value through insightfulness of data and identifying requirements for motivation clarification steps to ensure outputs were meaningful. This process served to maintain the visible context of design decisions as they were being encountered and addressed. The decision tree approach in this case placed data availability as the basis of the conversation creation, thus mitigating some of the technical challenges around missing or inaccessible data highlighted by Kocielnik et al. (2018). However, as noted by the sprint leader in a post project interview, this approach placed some restrictions on the design itself in that it was difficult for users to move between sub journeys that were "not necessarily related". He suggested that use of smaller trees or state diagrams may help to mitigate this. (3) The ***entry points served as formalisation of previously constructed user motivations***, thus linking earlier stages of the design process into the tree as a resource drawn on to drive the development. (4) Decision trees provided a ***record and overview of the design*** at any point in time that simultaneously offered an account for that ongoing work, as well as an at-a-glance resource for the team. (5) Related to the previous point, decision trees offered a ***resource to support the development work*** from visual representation to realisation. The different roles within the team—of data scientist, developer and conversational content creator—all used the diagrams as a resource for elements of task management. This is especially clear with content creation, discussed in an interview with Edie, where she stated that each branch was attended to systematically with corresponding conversational entries being added into the chatbot platform.

Quite clearly from the demonstration of LEC's design work, decision trees also involve a great deal of sketching. Sketching is seen in the design literature (and HCI) as supporting reflective dialogue within the design decision making process Schon (1983); Cross (1999). The wide variety of realisation and mapping tools available to service designers Tassi (2009) also attests to the importance of visualisation for design. In this case decision trees are used to record and provide an overview of chatbot functionality in a similar way to the flows suggested by Shevat (2017). However, the team in study III had to engage in a process of *tailoring* decision tree diagrams to their project, thus providing them wider visibility over the entire infrastructure at hand. Here then, they used them for more than just mapping chatbot functionality: they became a central resource to facilitate infrastructuring work.

Decision tree use and the mapping of logic in this way has been mentioned within the academic chatbot literature Cameron et al. (2018); Castle-Green et al. (2020). In some cases it has been described as a simple approach to design that doesn't address the complexities of conversational interaction Grudin and Jacques (2019); Fadhil (2018). However, study III of this thesis highlights the importance of visualisation within the design work itself and a need for physical representations of service infrastructure which includes; data, interaction, and user action layers of a sociotechnical IoT infrastructure that support the reflective, relational tracing dialogue, inherent to this work. Where decision trees are considered to be 'too simplistic' for a project, other realisation methods may be required to support and situate the reflective reasoning of designers. Novel approaches need to consider the multifaceted and socially embedded aspects of decision trees in practice, rather than as an isolated data structure which can then be somewhat misleadingly critiqued as ‘simplistic’.

7.5 Expanding on the work of the digital plumber

In addition to the infrastructuring work discussed in section 7.4, study II (chapter 5) of this thesis also surfaced design related responsibilities within the role of the professional digital plumber. The digital plumbing responsibilities uncovered through accounts of a project team addressing and resolving trouble experienced by professional ‘digital plumbers’ go beyond that which has previously been reported (Tolmie et al., 2010; Castelli et al., 2021). As such this thesis also contributed to knowledge by expanding our understanding of the digital plumbing role within professional contexts. This section further elaborates on this contribution.

Current conceptions of the work of digital plumbing are based around the physical installation of IoT technologies within a particular setting. This work was initially described by Tolmie et al. (2010) as the work involved in deployment of ubiquitous computing systems within peoples’ homes. Their descriptions of this were based on work performed by researchers within a research through design project involving installation of a sensor based monitoring system within real homes. In contrast Castelli et al. (2021) considers the work of digital plumbing within a commercial manufacturing setting. Both of these studies differ from the case study reported in chapter 5 of this thesis in that for WISP’s digital plumbers the work was an ongoing task of expanding the wider site network within new dwellings. In this way, this work of digital plumbing was a mundane everyday task for them in a similar way to the maintenance tasks described by Orr (1996) in his descriptions of the work of photocopy engineers. WISP's engineers were familiar with the site, the wider infrastructure and the types of dwellings they were working with. They had tools, knowledge-bases and established work processes in place.

The challenges reported from study II relate to the development of a new installation process that incorporates an RFID tag to be used by the digital plumber to set the channel of the device. The key fob is both a new physical tool for the digital plumber *and* part of the information layer of the infrastructure itself. Its purpose is to transfer knowledge in the form of data from the on-site engineer to the software on the HUB, essentially providing a link between the maintenance work process and technological layers of the Alert solution. However, although the fob was central to the design change being made, curiously it did *not* feature as part of the design process and was not treated as an object of design in and of itself. So, the RFID tag as a solution draws on built-in capabilities of the devices, effectively embodying standards that already exist within the current solution. It was therefore the surrounding work of digital plumbing and the associated software processes that were the subject of change.

Within this work Tom, the Technical Operations Manager, held a key role during the entire redesign process, from initially raising the trouble experienced during the field trials right through to executing and communicating the change to the engineering team. As part of this role of Digital Plumbing Representative, Tom had a number of responsibilities to fulfill. Firstly, he needed to raise the issue as worthy of a meeting, then during the meeting, further escalate this as something which needed a resolution. This was achieved through providing accounts of a breakdown. In a way that resonates strongly with observations discussed by Orr (1996), Tom provided digital plumbing reports, i.e., details of specific installs which he had personally been involved in and where trouble had been encountered . He supported these accounts with logs from the internal device monitoring system and included enough information for the development team to identify whether this was a software bug or expected behaviour. Another responsibility held by Tom was that of knowledge sharing the constraints of the digital plumber's role and the current processes and procedures relevant to the task at hand. Further to this he identified and presented a solution based on an understanding of the channel knowledge accessible to the on-site engineer and the technical problem as it had been explained to him. Finally, Tom fulfilled the role of redesigning the installation work process to coincide with the planned technology changes.

The unpacking of Tom's role in this way, builds on the four major areas of digital plumbing work identified by Tolmie et al. (2010). These are preparatory work, assembly of tools and parts, management of contingency and coordination and awareness. While some of the design related duties identified in this thesis could potentially be seen as linked to the management of contingencies, due to the size of the responsibility involved in this aspect of Tom's work an additional area of supporting the facilitation of change is needed to fully represent this. In a similar vein to Pipek and Wulf (2009) the results here show that open communication channels between the digital plumbing team and internal development team is essential to support user-centered design through the communication of infrastructural visibilities and the assessment of stakeholder values. Thus indicating, it is essential, where modifications are being made to the installation or maintenance elements of the product, a digital plumbing representative is at the table. This is particularly necessary in cases such as this, where the project relates to a fully managed commercial IoT solution, to ensure consistency of service. These findings also build on more recent reports of the digital plumbing role within the professional context (Castelli et al., 2021) by highlighting further challenges faced by professional digital plumbers within industry settings. In this context the digital plumber is considered as a kind of super-user with facilitating change as a key part of the role. In the way that the WISP team set up field trials within Project Rock the field engineers were represented, by Tom, as a group that was expected to assess and feedback on the findings of the trial in relation to their work. This formalised field trial approach supported a detailed collaborative investigation when trouble was encountered, resulting in the conditions for process and technology changes to occur in tandem.

7.5.0.1 Other ways digital plumbing featured in this research

The digital plumbing metaphor is currently seen in relation to the installation and maintenance of physical devices and infrastructure. It therefore does not currently expand to include most secondary services as they sit on top of an infrastructure maintained by someone else. For example, in the case of the chatbot described in study III (chapter 6) of this thesis, digital plumbing did not feature as part of the design work. The product itself was being created as a secondary service that would run using an infrastructure of software and hardware platforms, including; Facebook, smart home devices and mobile phones. While the team were reliant on these platforms working properly to achieve their goal of delivering the chatbot service, they did not have control or responsibility over any of these external elements. The maintenance work involved in managing a commercial chatbot of this nature is extensive, but is software and data related only.

There were a few mentions of installation troubles reported within the practitioner interviews in Study I (chapter 4). These were not detailed enough to draw further conclusions about the role of the digital plumber but may provide a grounding for future research directions to explore. Challenges mentioned include; driver issues, considerations for embedding into certain types of infrastructures (such as, working with harsh environments, areas with variable connections, WiFi authentication designed for people rather than devices and political challenges relating to client IT departments).

7.6 Designing the IoT moving forwards

Key IoT design challenges identified within this thesis relate to the (in)visibility of products and services as part and parcel of ubiquitous sociotechnical infrastructures. Therefore a key challenge for designers is what to make visible to who. For example, as we have seen within this work, designers rely on visibility over the hidden infrastructural elements of these systems to enable them to 'do design'. Applying an information infrastructures lens Star and Ruhleder (1996) has provided demonstrations of the ways designers foreground the relationships between different infrastructural elements through the use of infrastructural inversion Bowker (1994), using both knowledge sharing and diagram sketching to uncover and maintain visibility. As seen across all three study chapters, normally 'hidden' elements of these products and services need to be made visible to different members of the project team to ensure that design takes into account the relevant business motivations and values. However, care must be taken to ensure that the motivation for visibility is not unduly influencing the design itself (as was seen with the demoability requirement of the data-driven chatbot in chapter 6).

Depending on the type of IoT product or service being designed, tensions may arise between the different sociotechnical elements of the system. Relationships between different elements need to be thoroughly explored to uncover these to address potential risks that may arise as the product is being designed, integrated and used within a wider sociotechnical infrastructure. These tensions not only between different stakeholders within the design process itself but also between the different elements and states of the product or service. They also extend into the wider infrastructures of the products, for example, as seen in section 4.5.2.2 in regards to the supply chain risks. Through the identification of these tensions it is possible to uncover and anticipate risk of future infrastructural breakdowns. That is, where hidden elements of the sociotechnical infrastructure become unintentionally visible in a way that disrupts use or hinders experience. By uncovering these tensions and anticipating future breakdowns it is possible to design in contingencies and mitigation to ensure that seamless design of a long-term IoT product service is achieved. For example, as demonstrated in chapter 4, tensions exist between the environmental context of use and the data connections and/or power supplies. Chapter 5 demonstrated tensions between service processes and connection algorithms. Finally, chapter 6 demonstrated tensions between data insights and user experience. Using a process of infrastructural inversion within the design work to draw out and trace the relations between the different elements of IoT systems is an effective way of anticipating and assessing infrastructural breakdowns.

This process is relevant both to designers in industry and for academics looking to create speculative design probes offering realistic seamless experiences to users. The studies within this thesis have demonstrated trouble shooting, context analysis and diagram sketching as methods of achieving visibility over these hidden relational tensions. In a practical sense, an awareness of these tensions early in the process can assist businesses and academic designers with creating more sensitivity within their design briefs and team structure to allow designers the space to explore and address tensions between elements. As demonstrated in chapter 6 and supported in the chatbot literature Grudin and Jacques (2019), rigid design briefs and requirements for demonstrations of particular elements during design work can unduly influence the design process and outcomes.

These findings are also relevant to scholars and practitioners who are looking to support the design process with tools and methods that aid designers. Here, it is important to consider how to support the exploration of tensions between elements. The decision tree approach used in chapter 6 offered some support to the team by focusing the design reasoning onto the relations between data and users, however, it also restricted the design somewhat. Future research is needed here to better explore tools and methods that can focus design work on identifying and addressing these tensions without unduly restricting the user journeys of the product itself.

7.7 Summary of key contributions

This section briefly summarises the key contributions of this thesis.

1. Identification of design challenges and relational tensions within the process of IoT design and methods of foregrounding them. Building on previous work identifying tensions (Lee et al., 2018; Leiva et al., 2019) within design teams.

2. Demonstrations of the generation and use of notions of elemental states as a form of infrastructuring work, which builds on previous discussions of infrastructural inversion (Bowker, 1994; Simonsen et al., 2020).

3. Demonstrations of the use of decision trees in infrastructuring and data-work to help situate and anticipate customer responses to data insights. Thus expanding on previous descriptions of data-work and its related challenges (Fischer et al., 2017).

4. Identification of responsibilities within the role of the professional digital plumber working in a PSS capacity, which differ from those already identified in other contexts (Tolmie et al., 2010; Castelli et al., 2021)

7.8 Implications of this research

This section presents implications of this research for IoT design practitioners, policy makers and academics that support them through the generation of tools, methods and frameworks.

As complex sociotechnical infrastructures IoT services are, more often than not, working with an installed base. This base is in the form of physical networks and social organisation as well as with existing products. As part of this wider sociotechnical infrastructure the modification and expansion of products and services is fraught with complexities and relational tension that need to be navigated as part of the design process. When projects are occasioned, core requirements of the projects must include compatibility with what is already there so as not to cause unnecessary friction, as was seen in chapter 5 with new functionality being at odds with the core objectives of the on-site digital plumber. From this perspective it is important to find **ways to foreground the differing stakeholder perspectives and service layers** to help situate design reasoning and to identify any potential relational tensions as early as possible in the design process.

Design methods and tools aimed at supporting design practitioners within IoT contexts should consider how they can **support the use of notions of elemental state**. Within chapters 5 and 6 of this thesis members drew upon these notions as a way to navigate the tensions between different infrastructural layers and to anticipate future tensions that could be avoided. Within these examples the members self-organised to manage this through the generation of notions of elemental state that they could draw on as a resource for design. Standard design methods and frameworks which orient to this process may help to provide support in more structured manner. A research through design approach to develop and test supporting tools would be a useful way to expand on this work.

Chapter 6, surfaced challenges relating to the inflexibility of the design brief. The team had been tasked with creating a chatbot and as such were expected to follow conversational design conventions. However, tensions arose when this did not marry up with the conventions of communicating data-work. The lack of option to provide visualisations of the data caused the team difficulty as they were unable to achieve an acceptable level of user experience without breaking these conventions and providing visualisations through a downloadable PDF. From a practical perspective **flexible design briefs** should be provided to key members of the team earlier in the process to **allow relational tracing activities to have more impact on the project direction** from the start. For example, in this case receiving briefs and facilitating relational tracing discussions prior to the technology selection could have allowed tensions to be foregrounded and appropriately resolved.

Tensions have been identified in this thesis between a number of different object universes within IoT design teams. It is essential that **good communication channels** are maintained between these different stakeholders, particularly for drawing on and reporting infrastructural breakdowns and uncovering tensions. The field trials used by WISP provided a good platform for this communication and enabled the project team to review changes and then come together to collectively solve problems that had arisen as a result of the design change. In this way, the WISP team supported user-led design through treating digital plumbers as a type of super-user and **providing contextual knowledge about breakdown situations** to aid solution generation. This review approach could be useful to practitioners within other settings as a form of internal user testing and feedback process, specifically focused on surfacing relational tensions.

Finally, the decision trees used by the LEC team served a number of purposes in the way they supported the design process. In particular, this suggests that **diagram use for visualisation of IoT infrastructural layers to situate design and surface tensions** is a useful design resource which serves as more than just user journey mapping. Researchers and practitioners looking to support this element of the work through platforms, tools or new methods should consider how their methods might:

- Provide a central hub for the team

- Support design reasoning and development work
- Restrict design, for example, in this case the approach ended up forcing users in a particular direction, with limited ability for them to move across topics without starting again.
- Support data-work, the diagrams here aided reasoning about data meanings and presentation as well as user interactions with the system itself. Previous conversational diagrams have been designed to support conversation generation but not IoT data-work that may also be required (Shevat, 2017).
- Represent the user; typifications in LEC's case were technocentric. This allowed data access problems to be factored out by designing based on data availability but at the same time this took away the user focus. A balance would be beneficial here.

7.9 Limitations and future work

This section considers the limitations and scope of the research contained within this thesis. Firstly, as noted in the introduction and literature review chapters, the IoT is a vast industry that is now prevalent in all sectors and verticals to some degree. It would not be possible to capture the design challenges for this in its entirety. It was therefore necessary to focus the research in specific areas. The approach of the industry overview study in chapter 4 provided a foundation of a broad spectrum of challenges from which to focus. As a result of this and the identified gaps in the literature around the long-term challenges of working with deployed infrastructural systems, the two projects were selected as case studies from which to unpack IoT design work in practice.

As mentioned in chapter 3 gaining access to design teams for ethnographic research is challenging in itself and as such, it does place some limitations on this research. However, even without these access challenges the depth and breadth of the IoT industry means it is not realistic to attempt to study the full range of challenges and settings in detail. In focusing this research on the longer-term aspects of IoT design work, such as maintenance and data reuse, some of the design challenges relating to new product design have been only briefly mentioned or completely overlooked. For example, the detail surrounding tensions between hardware and software design approaches has not been addressed in detail and challenges of end user interaction design for new device based products has only been briefly touched upon.

While the studies in this thesis do not provide a huge level of breadth across the IoT industry they do provide a great deal of depth through unpacking of the 'machineries of interaction' using an ethnomethological approach. Therefore, the findings presented in this thesis can be seen as generalizeable in the sense that the everyday mundane collaborative work it depicts is recognisable in its ordinary nature by members of the setting and competent observers (Crabtree et al., 2013). Thereby, this thesis presents key generalizable features of IoT design from an adequate amount of fieldwork. However, there are still many opportunities to build upon this research. Future studies in this area would add weight to our understandings of IoT design practice, thereby providing even more purchase to IoT design practitioners and those looking to support them through the generation of theory, methods, frameworks and policy.

An example of future work opportunity lies in the challenge of supply chain complexities within the IoT introduce risk to the design process, particularly in relation to the long-term support predictions. The interview study, reported in chapter 4, highlighted a number of challenges in relation to this. Three core ways of working were identified as; a bespoke approach where business custom make the whole product, a cobbled approach where businesses use off the shelf parts and secondary service approaches working with 3rd party hardware either as a delivery mechanism or for data collection. WISP took the bespoke approach to their system development which gave them visibility and maintained control over the product service layers of the infrastructure. LEC on the other-hand took the secondary service approach of relying on 3rd party hardware to generate data. This thesis did not look in detail at the cobbled approach, however, indications from the interview study show that un-predicted supplier changes can have a huge impact on a cobbled approach from a long-term deployment perspective.

There is potential for these supply chain challenges to increase in their impact on IoT design, as pressure groups such as Which? (McCallum, 2023) push businesses towards upfront declarations of support times. The uncertainty that arises from this approach makes it very difficult for businesses and design teams to be able to confidently declare these support times due to a lack of visibility over long-term commercial viability. For governments, policy makers and pressure groups to be successful in making this policy change, which is clearly very important from an environmental and consumer perspective, it is crucial for more research to be carried out in relation to how to support designers and businesses. Particularly with addressing these challenges of supply chain uncertainty within the design process to enable them to have enough confidence of ongoing commercial viability to make these guarantees.

Questions also remain open in relation to the tensions between the traditional engineering and software approaches. This was something identified in the interview studies that has not been followed through in the subsequent ethnographic work due to the lack of hardware development work included in it. It is however notable from the alarm modification study described in chapter 5 that struggles do exist in relation to the permanence of hardware and fluidity of software when it comes to modification and ongoing development of deployed systems. That the team needed to silo code in order to maintain the functionality over a hardware module which did not have the RFID capabilities built in is indicative of the challenges arising from these differences. Further research is required to fully explore these challenges to continue to build on our understanding of the complex nature of IoT design work in practice.

Chapter 8

Conclusion

This thesis has presented exploratory research around the commercial design practices in the IoT. Products and services within this space have been identified as presenting unique challenges for designers due to their sociotechnical complexities and layered nature. A diverse set of actors must come together to design these multifaceted products and services which may include, hardware engineers, software engineers, technicians, product owners, network specialists, data scientists, user interface (UI) designers, solutions architects and field engineers. Within both the academic and industry literature, IoT devices are often thought of and described with a focus on the technology layers. However, the ever expanding network of embedded devices into our daily lives and routines contextualises this as a simplistic view which fails to take into account the sociotechnical complexities of these products and services, that must be navigated by the multi-disciplinary design teams working with them. For this reason, an information infrastructure perspective is well suited to understanding the work of design in this context.

The literature review in chapter 2, demonstrates how, as a nascent industry, the IoT has not received much attention from a design practice perspective within the literature. As the IoT literature is spread across many domains, three key areas of literature are identified as having gaps that are addressed by this work. Firstly, the field of ubiquitous computing has only recently begun to move beyond the lab to properly explore the embedded nature of IoT products ‘in the wild’. While a number of key design challenges have been identified via this stream, the research here has focused on either research deployments or user studies of commercial devices. The studies in chapters 5 and 6 build on this body of literature through the presentation of practice studies from a design perspective. Secondly, a body of design research has not yet focused in detail on the unique design space that the IoT creates for designers. Finally, the literature in the field of information infrastructures has begun to move into looking at practice based design studies, however this tends to take a broad view. These studies might include an element of IoT technology within the infrastructure in focus, however, they do not focus in on detail at the commercial practices of IoT product and service design. Thus the research within this thesis begins to address these gaps.

In response to these gaps in the literature this thesis addresses three research questions. Through this the aim of this research is to explore the sociotechnical design challenges faced by design practitioners within the field of the IoT and *their* methods of addressing them. This is with the intention of providing insights for the purpose of informing the creation of frameworks, practices, policy and further academic research into the work of designing the IoT. The research questions that guided the work are:

- How do IoT related design teams organise their work?
- What design challenges are being faced when designing for the IoT within a commercial context?
- What design practices are being applied to IoT related design work within these settings, and how?

To address these questions three empirical studies of industry based, IoT related design work are presented in chapters 4,5 and 6. The first study, as described in chapter 4, offers an industry overview as a foundation for two in depth ethnomethodologically informed studies of IoT design practice. These case studies serve to unpack design practices at a deeper level than those uncovered in the industry overview, through uncovering the natural accountability of design work in this context. As detailed in chapters 2 and 3 this approach to investigating design work is appropriate in this context as a way to inform the design of tools, frameworks and methods designed to support IoT design work.

The approach to this empirical work attempts to provide a broad view of the challenges encountered by design practitioners in this field. Chapters 5 and 6 then delved deeper into the challenges relating to the long-term nature of the IoT and challenges of working with IoT data streams to create a secondary service. The subjects of these involved commercial projects to; modify the installation process of an IoT alarm system and create a data-driven chatbot, respectively. The findings of which demonstrated *how* practitioners undertook infrastructuring work in practice, resulting in the following contributions to knowledge:

1. Identification of IoT design challenges within industry settings, in particular those relating to the longer term infrastructural nature of these product service systems.

2. Demonstration of relational tensions within the process of IoT design and descriptions of members' methods of foregrounding them. Building on previous work identifying tensions (Lee et al., 2018; Leiva et al., 2019) within design teams.

3. Demonstrations of the members' generation and use of notions of elemental states as a form of infrastructuring work, which builds on previous discussions of infrastructural inversion (Bowker, 1994; Simonsen et al., 2020).

4. Demonstrations of the use of decision trees as members' methods in infrastructuring and data-work to help situate and anticipate customer responses to data insights. Thus expanding on previous descriptions of data-work (Fischer et al., 2017) and decision tree use Shevat (2017).

5. Identification of responsibilities within the role of the professional digital plumber working in a PSS capacity, which differ from those already identified in other contexts (Tolmie et al., 2010; Castelli et al., 2021).

This thesis highlights IoT product service systems as complex sociotechnical infrastructures which require infrastructuring work to anticipate potential future breakdowns so as to design in mitigation and contingency. In practice, IoT designers must navigate a series of relational tensions between different elements of the system to successfully achieve this. Chapters 5 and 6 demonstrated two methods of doing this; through the use of knowledge sharing between stakeholders as a way to explore and draw on historical breakdowns, and through a process of using diagrams to map relationship and anticipate subsequent reactions. Designers working with these complex infrastructures must collaborate to take into account the different conflicting aspects in order to assess future infrastructural breakdown risk.

There are of course limitations to this work, as there is with any ethnography focused study of this nature. The IoT is a vast industry that is now prevalent in all sectors and verticals to some degree. It would not be possible to capture the design challenges for this in its entirety. In addition, a key challenge with any study of this nature is gaining access to design teams for ethnographic research. This is discussed in detail in chapter 3. However, even without these access challenges the depth and breadth of the IoT industry means it is not realistic to attempt to study the full range of challenges and settings in detail. It was therefore necessary to focus the research in specific areas. The two projects presented as case studies in chapters 5 and 6 were carefully selected as relevant to the challenges identified within chapter 4. In focusing this research on the longer-term aspects of IoT design work, such as maintenance and data reuse, some of the design challenges relating to new product design have been only briefly mentioned or completely overlooked. For example, the detail surrounding tensions between hardware and software design approaches has not been addressed in detail and challenges relating to end user interaction design for new device based products has only been briefly touched upon. While these may be seen as limitations of this work they are also opportunities that this work has uncovered as potential future research directions.

While the studies in this thesis do not provide a huge level of breadth across the IoT industry they do provide a great deal of depth through unpacking of the 'machineries of interaction' using an ethnomethological approach. Through this, the everyday mundane collaborative work it depicts is recognisable in its ordinary nature by members of the setting and competent observers (Crabtree et al., 2013). While this work presents a small but adequate amount of fieldwork in this sense, there are still many opportunities to build upon this research. Future studies in this area would add weight to our understanding of IoT design practice, thereby providing even more purchase to IoT design practitioners and those looking to support them through the generation of theory, methods, frameworks and policy.

Bibliography

Ali, Z. H., Ali, H. A., and Badawy, M. M. (2015). Internet of things (IoT): definitions, challenges and recent research directions. *International Journal of Computer Applications*, 128(1):37–47.

Alladi, T., Chamola, V., Sikdar, B., and Choo, K.-K. R. (2020). Consumer IoT: Security vulnerability case studies and solutions. *IEEE Consumer Electronics Magazine*, 9(2):17–25.

Ashton, K. et al. (2009). That 'internet of things' thing. *RFID journal*, 22(7):97–114.

Askoxylakis, I. (2018). A framework for pairing circular economy and the internet of things. In *2018 IEEE International Conference on Communications (ICC)*, pages 1–6. IEEE.

Atlam, H. F. and Wills, G. B. (2020). IoT security, privacy, safety and ethics. *Digital twin technologies and smart cities*, pages 123–149.

Becker, H. S. (1976). Art worlds and social types. *American behavioral scientist*, 19(6):703–718.

Bentley, R., Hughes, J. A., Randall, D., Rodden, T., Sawyer, P., Shapiro, D., and Sommerville, I. (1992). Ethnographically-informed systems design for air traffic control. In *Proceedings of the 1992 ACM conference on Computer-supported cooperative work*, pages 123–129.

Blevis, E. (2007). Sustainable interaction design: invention & disposal, renewal & reuse. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, pages 503–512.

Blomberg, J. and Karasti, H. (2013). Reflections on 25 years of ethnography in cscw. *Computer supported cooperative work (CSCW)*, 22:373–423.

Bødker, S., Dindler, C., and Iversen, O. S. (2017). Tying knots: Participatory infrastructuring at work. *Computer Supported Cooperative Work (CSCW)*, 26(1-2):245–273.

Bowker, G. (1994). Information mythology and infrastructure. *Information acumen: The understanding and use of knowledge in modern business*, 1994:231–247.

Bowker, G. C., Baker, K., Millerand, F., and Ribes, D. (2009). Toward information infrastructure studies: Ways of knowing in a networked environment. In *International handbook of internet research*, pages 97–117. Springer.

Boyatzis, R. E. (1998). *Transforming qualitative information: Thematic analysis and code development.* sage.

Boyes, H., Hallaq, B., Cunningham, J., and Watson, T. (2018). The industrial internet of things (IIoT): An analysis framework. *Computers in industry*, 101:1–12.

Brand, S. (1995). *How buildings learn: What happens after they're built.* Penguin.

Braun, V. and Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative research in psychology*, 3(2):77–101.

Brereton, M., Soro, A., Vaisutis, K., and Roe, P. (2015). The messaging kettle: Prototyping connection over a distance between adult children and older parents. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, pages 713–716.

Brown, N. (2018). Evaluating the usefulness of the adapted thematic analysis in the process of design. In *Proceedings of the 32nd International BCS Human Computer Interaction Conference 32*, pages 1–5.

Bucciarelli, L. L. (1988). An ethnographic perspective on engineering design. *Design studies*, 9(3):159–168.

Burkitt, F. (2014). *A strategist's guide to the Internet of Things.* Number 77. Strategy+ Business.

Button, G. (2000). The ethnographic tradition and design. *Design studies*, 21(4):319–332.

Button, G., Crabtree, A., Rouncefield, M., and Tolmie, P. (2015). Deconstructing ethnography. *Towards a social methodology for ubiquitous computing and interactive systems design. Dodrecht: Springer.*

Button, G. and Sharrock, W. (2009). Studies of work and the workplace in hci: Concepts and techniques. *Synthesis Lectures on Human-Centered Informatics*, 2(1):1–96.

Cameron, G., Cameron, D., Megaw, G., Bond, R., Mulvenna, M., O'Neill, S., Armour, C., and McTear, M. (2018). Back to the future: lessons from knowledge engineering methodologies for chatbot design and development. In *British HCI Conference 2018*.

Campbell, R., Al-Muhtadi, J., Naldurg, P., Sampemane, G., and Dennis Mickunas, M. (2002). Towards security and privacy for pervasive computing. In *International Symposium on Software Security*, pages 1–15. Springer.

Castelli, N., Pinatti de Carvalho;, A. F., Vitt;, N., Taugerbeck;, S., Randall;, D., Tolmie;, P., Stevens;, G., and Wulf, V. (2021). On technology-assisted energy saving: challenges of digital plumbing in industrial settings. *Human–Computer Interaction*, pages 1–29.

Castle-Green, T., Reeves, S., Fischer, J. E., and Koleva, B. (2020). Decision trees as sociotechnical objects in chatbot design. In *Proceedings of the 2nd Conference on Conversational User Interfaces*, pages 1–3.

Clarke, V. and Braun, V. (2013). Teaching thematic analysis: Overcoming challenges and developing strategies for effective learning. *The psychologist*, 26(2).

Coley, F., Houseman, O., and Roy, R. (2007). An introduction to capturing and understanding the cognitive behaviour of design engineers. *Journal of Engineering Design*, 18(4):311–325.

Costa, C. A. d., Yamin, A. C., and Geyer, C. F. R. (2008). Toward a general software infrastructure for ubiquitous computing. *IEEE pervasive computing: mobile and ubiquitous systems. Los Alamitos. Vol. 7, n. 1 (Jan.-Mar. 2008), p. 64-73.*

Coulton, P., Lindley, J. G., Gradinar, A. I., Colley, J., Sailaja, N., Crabtree, A., Forrester, I., and Kerlin, L. (2019). Experiencing the future mundane. *Proceedings of RTD*, 10.

Crabtree, A., Lodge, T., Colley, J., Greenhalgh, C., Glover, K., Haddadi, H., Amar, Y., Mortier, R., Li, Q., Moore, J., et al. (2018). Building accountability into the internet of things: the IoT databox model. *Journal of Reliable Intelligent Environments*, 4:39–55.

Crabtree, A. and Rodden, T. (2004). Domestic routines and design for the home. *Computer Supported Cooperative Work*, 13(2):191–220.

Crabtree, A., Rodden, T., Tolmie, P., and Button, G. (2009). Ethnography considered harmful. In *Proceedings of the SIGCHI conference on human factors in computing systems*, pages 879–888.

Crabtree, A., Rouncefield, M., and Tolmie, P. (2012). *Doing design ethnography*. Springer.

Crabtree, A., Tolmie, P., and Rouncefield, M. (2013). "how many bloody examples do you want?" fieldwork and generalisation. In *ECSCW 2013: Proceedings of the 13th European Conference on Computer Supported Cooperative Work, 21-25 September 2013, Paphos, Cyprus*, pages 1–20. Springer.

Crabu, S. and Magaudda, P. (2018). Bottom-up infrastructures: Aligning politics and technology in building a wireless community network. *Computer Supported Cooperative Work (CSCW)*, vol. 27(no. 2):149–176.

Crilly, N., Moultrie, J., and Clarkson, P. J. (2009). Shaping things: intended consumer response and the other determinants of product form. *Design studies*, 30(3):224–254.

Cross, N. (1999). Natural intelligence in design. *Design studies*, 20(1):25–39.

Darshan, K. and Anandakumar, K. (2015). A comprehensive review on usage of internet of things (IoT) in healthcare system. In *2015 International Conference on Emerging Research in Electronics, Computer Science and Technology (ICERECT)*, pages 132–136. IEEE.

de Carvalho, P. and Fabiano, A. (2021). Thematic analysis for interactive systems design: A practical exercise. In *Proceedings of 19th European Conference on Computer-Supported Cooperative Work*. European Society for Socially Embedded Technologies (EUSSET).

Desjardins, A., Wakkary, R., and Odom, W. (2015). Investigating genres and perspectives in hci research on the home. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, pages 3073–3082.

Dickson, G. and Stolterman, E. (2016). Why design method development is not always carried out as user-centered design. In *Proceedings of* *the 2016 CHI Conference on Human Factors in Computing Systems*, pages 4056–4060.

Dillahunt, T. R. and Mankoff, J. (2014). Understanding factors of successful engagement around energy consumption between and among households. In *Proceedings of the 17th ACM conference on Computer supported cooperative work & social computing*, pages 1246–1257.

Dorst, K. (2011). The core of 'design thinking'and its application. *Design studies*, 32(6):521–532.

Dourish, P. (2004). What we talk about when we talk about context. *Personal and ubiquitous computing*, 8(1):19–30.

Endmann, A. and Keßner, D. (2016). User journey mapping–a method in user experience design. *i-com*, 15(1):105–110.

Fadhil, A. (2018). Can a chatbot determine my diet?: Addressing challenges of chatbot application for meal recommendation. *arXiv preprint arXiv:1802.09100*.

Fischer, J. E., Costanza, E., Ramchurn, S. D., Colley, J., and Rodden, T. (2014). Energy advisors at work: charity work practices to support people in fuel poverty. In *Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing*, pages 447–458.

Fischer, J. E., Crabtree, A., Colley, J. A., Rodden, T., and Costanza, E. (2017). Data work: how energy advisors and clients make IoT data accountable. *Computer Supported Cooperative Work (CSCW)*, 26:597–626.

Fischer, J. E., Crabtree, A., Rodden, T., Colley, J. A., Costanza, E., Jewell, M. O., and Ramchurn, S. D. (2016). "just whack it on until it gets hot": Working with IoT data in the home. New York, NY, USA. Association for Computing Machinery.

Fischer, J. E., Reeves, S., Porcheron, M., and Sikveland, R. O. (2019). Progressivity for voice interface design. In *Proceedings of the 1st International Conference on Conversational User Interfaces*, pages 1–8.

Fox, A., Davies, N., de Lara, E., Spasojevic, M., and Griswold, W. (2006). Real-world ubicomp deployments: Lessons learned. *IEEE Pervasive Computing*, 5(3):21–23.

Fox, S. E., Silva, R. M., and Rosner, D. K. (2018). Beyond the prototype: Maintenance, collective responsibility, and public IoT. In *Proceedings of the 2018 Designing Interactive Systems Conference*, pages 21–32.

Friedewald, M. and Raabe, O. (2011). Ubiquitous computing: An overview of technology impacts. *Telematics and Informatics*, 28(2):55–65.

Garfinkel, H. (1967). Studies in ethnomethodology. *Prentice-Hall*.

Garfinkel, H. (2002). *Ethnomethodology's program: Working out Durkheim's aphorism*. Rowman & Littlefield Publishers.

Garfinkel, H. and Livingston, E. (2003). Phenomenal field properties of order in formatted queues and their neglected standing in the current situation of inquiry. *Visual Studies*, 18(1):21–28.

Garfinkel, H. and Wieder, L. D. (1992). Two incommensurable asymmetrically alternate technologies of social analysis. *Text in context: Contributions to ethnomethodology*, pages 175–206.

Gaver, B., Dunne, T., and Pacenti, E. (1999). Design: cultural probes. *interactions*, 6(1):21–29.

Gokhale, P., Bhat, O., and Bhat, S. (2018). Introduction to IoT. *International Advanced Research Journal in Science, Engineering and Technology*, 5(1):41–44.

Goodman, E., Stolterman, E., and Wakkary, R. (2011). Understanding interaction design practices. In *Proceedings of the SIGCHI conference on human factors in computing systems*, pages 1061–1070.

GOV.UK (2018). Code of practice for consumer IoT security.

Gray, C. M., Stolterman, E., and Siegel, M. A. (2014). Reprioritizing the relationship between hci research and practice: bubble-up and trickle-down effects. In *Proceedings of the 2014 conference on Designing interactive systems*, pages 725–734. ACM.

Grinter, R. E., Edwards, W. K., Chetty, M., Poole, E. S., Sung, J.-Y., Yang, J., Crabtree, A., Tolmie, P., Rodden, T., Greenhalgh, C., et al. (2009). The ins and outs of home networking: The case for useful and usable domestic networking. *ACM Transactions on Computer-Human Interaction (TOCHI)*, 16(2):1–28.

Grudin, J. and Jacques, R. (2019). Chatbots, humbots, and the quest for artificial general intelligence. In *Proceedings of the 2019 CHI conference on human factors in computing systems*, pages 1–11.

Gubbi, J., Buyya, R., Marusic, S., and Palaniswami, M. (2013). Internet of things (IoT): A vision, architectural elements, and future directions. *Future generation computer systems*, 29(7):1645–1660.

Hales, D. (2013). Design fictions an introduction and provisional taxonomy. *Digital Creativity*, 24(1):1–10.

Haugeland, I. K. F., Følstad, A., Taylor, C., and Bjørkli, C. A. (2022). Understanding the user experience of customer service chatbots: An experimental study of chatbot interaction design. *International Journal of Human-Computer Studies*, 161:102788.

Heath, C., Hindmarsh, J., and Luff, P. (2010). Analysing video: Developing preliminary observations. *Video in qualitative research: Analysing social interaction in everyday life*, pages 61–86.

Heath, C. and Luff, P. (1992). Collaboration and control crisis management and multimedia technology in london underground line control rooms. *Computer Supported Cooperative Work (CSCW)*, 1:69–94.

Hossein Motlagh, N., Mohammadrezaei, M., Hunt, J., and Zakeri, B. (2020). Internet of things (IoT) and the energy sector. *Energies*, 13(2):494.

Hughes, E. C. (1958). Men and their work. *American Sociological Review.*

IoTSF (2016). IoT security foundation publishes best practice guidelines for consumer products and vulnerability disclosure.

Kakkar, L., Gupta, D., Saxena, S., and Tanwar, S. (2021). IoT architectures and its security: a review. In *Proceedings of the Second International Conference on Information Management and Machine Intelligence: ICIMMI 2020*, pages 87–94. Springer.

Kamilaris, A., Gao, F., Prenafeta-Boldu, F. X., and Ali, M. I. (2016). Agri-IoT: A semantic framework for internet of things-enabled smart farming applications. In *2016 IEEE 3rd World Forum on Internet of Things (WF-IoT)*, pages 442–447. IEEE.

Karasti, H. (2014). Infrastructuring in participatory design. In *Proceedings of the 13th Participatory Design Conference: Research Papers-Volume 1*, pages 141–150.

Karasti, H. and Blomberg, J. (2018). Studying infrastructuring ethnographically. *Computer Supported Cooperative Work (CSCW)*, vol. 27(no. 2):233–265.

Karasti, H., Pipek;, V., and Bowker, G. C. (2018). An afterword to 'infrastructuring and collaborative design'. *Computer Supported Cooperative Work (CSCW)*, vol. 27(no. 2):267–289.

Karasti, H. and Syrjänen, A.-L. (2004). Artful infrastructuring in two cases of community pd. In *Proceedings of the eighth conference on Participatory design: Artful integration: interweaving media, materials and practices-Volume 1*, pages 20–30.

Karie, N. M., Sahri, N. M., and Haskell-Dowland, P. (2020). IoT threat detection advances, challenges and future directions. In *2020 workshop on emerging technologies for security in IoT (ETSecIoT)*, pages 22–29. IEEE.

Kashani, M. H., Madanipour, M., Nikravan, M., Asghari, P., and Mahdipour, E. (2021). A systematic review of IoT in healthcare: Applications, techniques, and trends. *Journal of Network and Computer Applications*, 192:103164.

Kim, J. and Ryu, H. (2014). A design thinking rationality framework: Framing and solving design problems in early concept generation. *Human–Computer Interaction*, 29(5-6):516–553.

King, R., Churchill, E. F., and Tan, C. (2017). *Designing with data: Improving the user experience with A/B testing*. O'Reilly Media, Inc.

Kocielnik, R., Hsieh, G., and Avrahami, D. (2018). Helping users reflect on their own health-related behaviors. In *Studies in Conversational UX Design*, pages 85–115. Springer.

Korn, M. and Voida, A. (2015). Creating friction: infrastructuring civic engagement in everyday life. In *Proceedings of The Fifth Decennial Aarhus Conference on Critical Alternatives*, pages 145–156. Aarhus University Press.

Kuniavsky, M. (2010). *Smart things: ubiquitous computing user experience design*. Elsevier.

Kuutti, K. (2013). 'practice turn'and cscw identity. *ECSCW 2013 Adjunct Proceedings*, pages 39–44.

Kuutti, K. and Bannon, L. J. (2014). The turn to practice in hci: towards a research agenda. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 3543–3552. ACM.

Lam, K.-Y., Mitra, S., Gondesen, F., and Yi, X. (2021). Ant-centric IoT security reference architecture—security-by-design for satellite-enabled smart cities. *IEEE Internet of Things Journal*, 9(8):5895–5908.

Lamont, M. and Swidler, A. (2014). Methodological pluralism and the possibilities and limits of interviewing. *Qualitative sociology*, 37:153–171.

Lee, B., Cooper, R., and Hands, D. (2018). Are traditional npd processes relevant to IoT product and service development activities? a critical examination. In *Design Research Society Conference*.

Lee, B., Cooper, R., Hands, D., and Coulton, P. (2019a). Design drivers: A critical enabler to mediate value over the npd process within internet of things.

Lee, B., Cooper, R., Hands, D., and Coulton, P. (2019b). Value creation for IoT: challenges and opportunities within the design and development process.

Lee, B., Cooper, R., Hands, D., and Coulton, P. (2022). Continuous cycles of data-enabled design: reimagining the IoT development process. *AI EDAM*, 36.

Lee, J., Kao, H.-A., and Yang, S. (2014). Service innovation and smart analytics for industry 4.0 and big data environment. *Procedia Cirp*, 16:3–8.

Leiva, G., Maudet, N., Mackay, W., and Beaudouin-Lafon, M. (2019). Enact: Reducing designer–developer breakdowns when prototyping custom interactions. *ACM Transactions on Computer-Human Interaction (TOCHI)*, 26(3):1–48.

Liu, Y., Goncalves, J., Ferreira, D., Hosio, S., and Kostakos, V. (2014). Identity crisis of ubicomp? mapping 15 years of the field's development and paradigm change. In *Proceedings of the 2014 ACM International joint conference on pervasive and ubiquitous computing*, pages 75–86.

Lochmiller, C. R. (2021). Conducting thematic analysis with qualitative data. *Qualitative Report*, 26(6).

Lodato, T. J. (2015). *The work of user experience design: materiality and cultures in designing*. PhD thesis, Georgia Institute of Technology.

Lodge, T. and Crabtree, A. (2019). Privacy engineering for domestic IoT: Enabling due diligence. *Sensors*, 19(20):4380.

Loh, W.-Y. (2014). Fifty years of classification and regression trees. *International Statistical Review*, 82(3):329–348.

Lukowicz, P., Pentland, S., and Ferscha, A. (2011). From context awareness to socially aware computing. *IEEE pervasive computing*, 11(1):32–41.

Lynch, M. (1999). Silence in context: Ethnomethodology and social theory. *Human studies*, 22(2-4):211–233.

Magee, J. F. (1964). *Decision trees for decision making*. Harvard Business Review.

Malinowski, B. (1922). *Argonauts of the Western Pacific: An account of native enterprise and adventure in the archipelagoes of Melanesian New Guinea*. Routledge.

Martin, D. (2012). The cooperative use of material resources and contextual features in graphic design work. *Design Studies*, 33(6):589–610.

Martin, D., O'Neill, J., and Randall, D. (2009). 'talking about (my) generation': Creativity, practice, technology & talk. In *ECSCW 2009*, pages 171–190. Springer.

McCallum, S. (2023). Smart appliances could stop working after two years, says which? *BBC News*.

McCosker, A. and Wilken, R. (2014). Rethinking 'big data'as visual knowledge: the sublime and the diagrammatic in data visualisation. *Visual Studies*, 29(2):155–164.

Moore, R. J. and Arar, R. (2018). Conversational ux design: an introduction. In *Studies in Conversational UX Design*, pages 1–16. Springer.

Morgan, J. N. and Sonquist, J. A. (1963). Problems in the analysis of survey data, and a proposal. *Journal of the American statistical association*, 58(302):415–434.

Morse, J. M. (2010). Simultaneous and sequential qualitative mixed method designs. *Qualitative inquiry*, 16(6):483–491.

Morse, J. M. and Niehaus, L. (2009). Principles and procedures of mixed methods design. *Walnut Creek, CA: Left*.

Mortier, R., Haddadi, H., Henderson, T., McAuley, D., and Crowcroft, J. (2014). Human-data interaction: The human face of the data-driven society. *arXiv preprint arXiv:1412.6159*.

Mortier, R., Zhao, J., Crowcroft, J., Wang, L., Li, Q., Haddadi, H., Amar, Y., Crabtree, A., Colley, J., Lodge, T., et al. (2016). Personal data management with the databox: What's inside the box? In *Proceedings of the 2016 ACM Workshop on Cloud-Assisted Networking*, pages 49–54.

Nansen, B., van Ryn, L., Vetere, F., Robertson, T., Brereton, M., and Dourish, P. (2014). An internet of social things. In *Proceedings of the 26th Australian Computer-Human Interaction Conference on Designing Futures: the Future of Design*, pages 87–96.

Neumann, L. J. and Star, S. L. (1996). Making infrastructure: The dream of a common language. In *PDC'96 Proceedings of the Participatory Design Conference*, pages 231–240.

Norman, D. A. (2010). The research-practice gap: The need for translational developers. *interactions*, 17(4):9–12.

Odom, W., Wakkary, R., Lim, Y.-k., Desjardins, A., Hengeveld, B., and Banks, R. (2016). From research prototype to research product. In

Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems, pages 2549–2561.

Ojha, T., Misra, S., and Raghuwanshi, N. S. (2021). Internet of things for agricultural applications: The state of the art. *IEEE Internet of Things Journal*, 8(14):10973–10997.

Oliver, D. G., Serovich, J. M., and Mason, T. L. (2005). Constraints and opportunities with interview transcription: Towards reflection in qualitative research. *Social forces*, 84(2):1273–1289.

Orr, J. (1996). Talking about machines: An ethnography of a modern job. ith aca, ny.

Parmiggiani, E. (2015). Integration by infrastructuring: The case of subsea environmental monitoring in oil and gas offshore operations.

Patel, P., Ali, M. I., and Sheth, A. (2017). On using the intelligent edge for IoT analytics. *IEEE Intelligent Systems*, 32(5):64–69.

Philipose, M., Fishkin, K. P., Perkowitz, M., Patterson, D. J., Fox, D., Kautz, H., and Hahnel, D. (2004). Inferring activities from interactions with objects. *IEEE pervasive computing*, 3(4):50–57.

Pipek, V. and Wulf, V. (2009). Infrastructuring: Toward an integrated perspective on the design and use of information technology. *Journal of the Association for Information Systems*, 10(5):1.

Pycock, J. and Bowers, J. (1996). Getting others to get it right: an ethnography of design work in the fashion industry. In *Proceedings of the 1996 ACM conference on Computer supported cooperative work*, pages 219–228.

Randall, D., Rouncefield, M., and Tolmie, P. (2021). Ethnography, cscw and ethnomethodology. *Computer Supported Cooperative Work (CSCW)*, 30:189–214.

Reeves, S., Porcheron, M., Fischer, J. E., Candello, H., McMillan, D., McGregor, M., Moore, R. J., Sikveland, R., Taylor, A. S., Velkovska, J., et al. (2018). Voice-based conversational ux studies and design. In *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems*, pages 1–8.

Rejeb, A., Suhaiza, Z., Rejeb, K., Seuring, S., and Treiblmaier, H. (2022). The internet of things and the circular economy: A systematic literature review and research agenda. *Journal of Cleaner Production*, page 131439.

Rodden, T. and Benford, S. (2003). The evolution of buildings and implications for the design of ubiquitous domestic environments. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, pages 9–16.

Rowland, C., Goodman, E., Charlier, M., Light, A., and Lui, A. (2015). *Designing connected products: UX for the consumer Internet of Things*. O'Reilly Media, Inc.

Sacks, H. (1984). Notes on methodology. In Maxwell, J. and Heritage, J., editors, *Structures of social action: Studies in conversation analysis*, pages 21–27. Cambridge University Press, Cambridge.

Sacks, H. (1992). Harvey sacks: lectures on conversation. *Malden, MA: Blackwell Publishing*.

Sailaja, N., Crabtree, A., Colley, J., Gradinar, A., Coulton, P., Forrester, I., Kerlin, L., and Stenton, P. (2019). The living room of the future. In *Proceedings of the 2019 ACM International Conference on Interactive Experiences for TV and Online Video*, pages 95–107.

Schmidt, K. (2009). Divided by a common acronym: On the fragmentation of cscw. In *ECSCW 2009*, pages 223–242. Springer.

Schmidt, K. and Bannon, L. (1992). Taking cscw seriously: Supporting articulation work. *Computer Supported Cooperative Work (CSCW)*, 1:7–40.

Schon, D. A. (1983). *The reflective practitioner: How professionals think in action.* Ashgate Publishing.

Sethi, P. and Sarangi, S. R. (2017). Internet of things: architectures, protocols, and applications. *Journal of Electrical and Computer Engineering*, 2017.

Sharrock, W. and Anderson, B. (1994). The user as a scenic feature of the design space. *Design Studies*, 15(1):5–18.

Shevat, A. (2017). *Designing bots: Creating conversational experiences.* O'Reilly Media, Inc.

Simonsen, J., Karasti, H., and Hertzum, M. (2020). Infrastructuring and participatory design: Exploring infrastructural inversion as analytic, empirical and generative. *Computer Supported Cooperative Work (CSCW)*, 29(1):115–151.

Soro, A., Brereton, M., Dema, T., Oliver, J. L., Chai, M. Z., and Ambe, A. M. H. (2018). The ambient birdhouse: An IoT device to discover birds and engage with nature. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, pages 1–13.

Star, S. and Ruhleder, K. (1994). Steps towards and ecology of infrastructure: Complex problems in design and access for large-scale collaborative systems. In *ACM Conference on Computer-Supported Cooperative Work (CSCW'94), Chapel Hill, NC, ACM Press.*

Star, S. L. (1999). The ethnography of infrastructure. *American behavioral scientist*, 43(3):377–391.

Star, S. L. and Bowker, G. C. (2006). How to infrastructure. *Handbook of new media: Social shaping and social consequences of ICTs*, pages 230–245.

Star, S. L. and Ruhleder, K. (1996). Steps toward an ecology of infrastructure: Design and access for large information spaces. *Information systems research*, 7(1):111–134.

Steele, J. and Iliinsky, N. (2010). *Beautiful visualization: Looking at data through the eyes of experts*. O'Reilly Media, Inc.

Subasi, A., Radhwan, M., Kurdi, R., and Khateeb, K. (2018). IoT based mobile healthcare system for human activity recognition. In *2018 15th learning and technology conference (L&T)*, pages 29–34. IEEE.

Suchman, L. A. (1987). *Plans and situated actions: The problem of human-machine communication*. Cambridge university press.

Sudnow, D. (1993). *Ways of the hand: The organization of improvised conduct*. MIT Press.

Tassi, R. (2009). Service design tools. communication methods supporting design process.

Theodoridis, E., Mylonas, G., and Chatzigiannakis, I. (2013). Developing an IoT smart city framework. In *Information, intelligence, systems and applications (iisa), 2013 fourth international conference on*, pages 1–6. IEEE.

Tolmie, P., Crabtree, A., Egglestone, S., Humble, J., Greenhalgh, C., and Rodden, T. (2010). Digital plumbing: the mundane work of deploying ubicomp in the home. *Personal and Ubiquitous Computing*, 14(3):181–196.

Tolmie, P., Crabtree, A., Rodden, T., Colley, J., and Luger, E. (2016). "this has to be the cats": Personal data legibility in networked sensing systems. In *Proceedings of the 19th ACM Conference on Computer-Supported Cooperative Work & Social Computing*, pages 491–502. ACM.

Tolmie, P., Pycock, J., Diggins, T., MacLean, A., and Karsenty, A. (2002). Unremarkable computing. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, pages 399–406.

Vailshery, L. S. (2022). Number of IoT connected devices worldwide 2019-2021, with forecasts to 2030.

Vatsa, V. R. and Singh, G. (2015). A literature review on internet of things (IoT). *International Journal of Computer Systems*, 2(8):355–358.

Voulgaridis, K., Lagkas, T., Angelopoulos, C. M., and Nikoletseas, S. E. (2022). IoT and digital circular economy: Principles, applications, and challenges. *Computer Networks*, page 109456.

Walport, M. (2014). The internet of things: making the most of the second digital revolution. Technical report, The Government Office for Science.

Weiser, M. (1991). The computer for the 21 st century. *Scientific american*, 265(3):94–105.

Wong, S. C., Crowder, R. M., Wills, G. B., and Shadbolt, N. R. (2008). Knowledge transfer: from maintenance to engine design. *Journal of computing and information science in engineering*, 8(1).

Yin, C., Xiong, Z., Chen, H., Wang, J., Cooper, D., and David, B. (2015). A literature survey on smart cities. *Sci. China Inf. Sci.*, 58(10):1–18.

Yoo, Y., Lyytinen, K. J., Boland, R. J., and Berente, N. (2010). The next wave of digital innovation: Opportunities and challenges: A report on the research workshop'digital challenges in innovation research'.

Zimmerman, J., Forlizzi, J., and Evenson, S. (2007). Research through design as a method for interaction design research in hci. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, pages 493–502.