EXPLORING DESIGN IMPLICATIONS FOR IoT PRODUCTS AND SERVICE DEVELOPMENT THROUGH MULTIPLE CASE STUDY ANALYSIS.

Boyeun Lee, Rachel Cooper, David Hands, and Paul Coulton

b.lee12@lancaster.ac.uk, r.cooper@lancaster.ac.uk, d.j.hands@lancaster.ac.uk, p.coulton@lancaster.ac.uk
LICA Building, Lancaster University, Bailrigg, Lancaster LA1 4YD, UK

Abstract: Amalgamating sensors, actuators, and cloud computing with non-digital products and services is regarded as critical opportunities to lead innovation, transforming the conventional way of business activities, such as value creation, new product development (NPD), and design practices. However, a paucity of empirical studies examines IoT design challenges and practices across NPD process. Thus, this study aims to explore design practices and challenges for IoT development through investigating empirical data. The case study methodology is selected, as it is particularly appropriate for a phenomenological exploration of how IoT systems are developed. Through multiple case study, emerging patterns and themes on design challenges are recognised which are largely related to extra layers of development complexity with continuous process, and data management issues. A major contribution arising from this paper is to propose design challenges and implications for IoT systems development, which may unlock its value by selling physical products, providing customised services, and harnessing data arising from the product in use.

1. INTRODUCTION

Amalgamating sensors, actuators, and cloud computing with non-digital products and services is regarded as critical opportunities to lead innovation (Lasi et al., 2014; Radziwon et al., 2014). This novel type of sensor-embedded product, which exists in larger network ecologies, connecting both the digital and physical worlds, transforms the conventional way of business activities, including value creation, new product development (NPD), and associated design practices. There are several key factors which are related to and conditioning the business activities, for example, material properties of digitalised artefacts, dimensions of big data, and digital technologies and innovation (McAfee & Brynjolfsson, 2012; Yoo, 2010). Whilst the number of research studies focused on technical aspects of IoT are increasing, scholars from marketing and design argue that it is time to reframe a novel approach towards design for IoT system (Ng & Wakenshaw, 2017; Speed & Maxwell, 2015).

There are several studies on design in the context of data-enabled design or IoT development. In relation to data practice, Kandel et al (2012) identified design challenges and practices within data science process. From the field of architecture and design, Deutsch (2015), King et al. (2017), and Speed and Oberlander (2016) devise frameworks that illustrates the spectrum of combining data into design mindset or practice. Researchers from information systems argues design could be used as a medium of decoupling material properties, creating multiple affordances of digitised artefacts (Jonsson et al., 2009; Tilson et al., 2010; Yoo, 2010; Yoo et al., 2012). Regarding the concerns of security, privacy and trust, trustworthy design gains increasing attention from HCI and design scholars (Bhattacharya et al., 2017; Harte et al., 2014; Lin et al., 2011). However, there is a paucity of empirical studies that thoroughly understands IoT design challenges and practices across the stages of new product development (NPD). Therefore, to develop the field forward, a comprehensive understanding is required from the emerging phenomena of design and development practices.

For the study, three research questions are raised: a) what is design and what do designers do? b) what has been studied about the challenges and contributions of design in NPD process? In addition, c) what are the emerging design challenges and implications that we could learn from regarding IoT development? In order to answer these primary questions, this paper commences with an extensive examination of current literature and features a multiple case study investigation. The case study methodology is selected, as it is particularly appropriate for a phenomenon exploration (Yin, 2009) of how the complex digital and physical products are designed and developed. From the thematic analysis of empirical data, it is identified that there are extra layers of development complexity with value creation through data. This is because IoT design is not simply the combination of hardware-related features into software-based development, requiring designers to consider the complex ecologies and eternal NPD process.

A major contribution of this paper is to propose design challenges and implications for IoT systems development that may fully unlock its value by selling physical products, providing customised services, and harnessing data arising from the product in use. It will enable design scholars and practitioners to understand the nature of continuous IoT design and to consider the research outcome within the current IoT development practices. This paper is structured as follows. From the literature, different conceptualisation of design and designers are identified. Then the conventional and emerging challenges and contributions of design towards NPD process are explored. From the empirical study, design challenges and activities are identified and what are design implications within existing theories are then discussed.

2. THEORETICAL BACKGROUND

2.1 Design Contributions towards Traditional Product Development

What is Design?

Design is originated from the Latin *designo* meaning ‘to mark out, trace, plan’; ‘to point out, indicate, signify’; and ‘to portray or delineate’ (The University of Notre Dame, n.d.). As a discipline, design has a long history with its origins in art, architecture and industrial design, whereas, in literature design is regarded either a noun/outcome and a verb/process (Glanville, 2015; Steinitz, 1995; Talke et al., 2009). As a noun/outcome, design represents the final plan of action (a drawing or model), or the result of the product development process, such as objects appearance (Eisenman, 2013). ‘Design’ as a verb/process is understood as the act of developing appealing, usable and functional products which commonly requires substantial research, modelling, iterative adjustment, and redesign (Cecilia et al., 2008; Nijhuis & de Vries, 2019; Roper et al., 2016). In many academic papers, the stances of the discourse of what design is and what designers do are largely founded on three different accounts: Positivistic, Constructive and Pragmatic.

From the positivistic account design is considered as a scientific or engineering endeavour, adopting approaches and terminology of natural sciences, mathematics, and system theory (Fallman, 2003). This modern movement to scientise design emerged in the early 1920s and continued in the 1960s in which the focal point of the argument is on 'scientific process' for problem-solving (Cross, 2001). Within this account, a designer is defined as 'everyone designs who devises courses of action aimed at changing existing situation into preferred ones (Simon, 1969).' Constructive account of design gains interest from researchers while a positivist perspective is being criticised as it is not applicable to 'wicked problems (H. Rittel, 1972)' but only be applied to well-defined problems already extracted from a situation of practice (Schön, 1983). Fallman (2003) used 'black-box' as a metaphor of Design which represents the design process is steered by a designer's values and preferences (Schön, 1983) depending on their individuality, aesthetics, and individual judgement (Cecilia et al., 2008).

Within the third strand, design is considered as a hermeneutic process of interpretation and the creation of meaning (Fallman, 2003) and designers have constructive and reflective skills (Cecilia et al., 2008). From the pragmatic perspective, Rittel and Webber (1973) argue that design is not only proposing solutions to problems, but should be an argumentative process. Aligned with this, Klaus Krippendorf (1989) also suggests design as 'making sense (of things)'. Although we understand the conception of design which is based on three distinctive accounts of what design is and how designers do, we still have an unanswered question in mind 'how does design contribute to value creation within the context of new product development?'. Consequently, the next section explores existing research on the design contributions and challenges in product development process.

Design Contributions towards Conventional Product Development

Conventionally, when design was primarily understood as a form and function, organisational value was created with the push economy where linear and sequential development processes are prominent. Over the sequential product development process, designers' involvement was restricted to early and late stages, focussing on the functional aspects of product development and branding (Perks et al., 2005). The industrial designers contribution to organisational value creation by anticipating and developing best-guessed products (Speed & Maxwell, 2015). Once the best guessed goods are graphically rendered, it is then passed to engineers and designers modify them as manufactural without much deliberation on the aesthetic or human aspects of the product (Braham, 1992). Before launching the product to the market, designers are also involved in marketing, designing a logo, improving type styling and colours to stamp a unique identity and brand which secure a place on the shelves of shops (Speed & Maxwell, 2015). With this push strategy, firms continuously sell the next product and keep making profits because the product being sold becomes obsolete over time (Hui, 2014).

Whilst the economic paradigm has been evolved from the push economy to the pull and push-pull economy, the traditional sequential NPD approach was deliberately superseded by the concurrent, spiral and agile approach that has more emphasis on simultaneous running with a cross-functional approach; external network interactions; iterative, rapid and lightweight process; and reviews and iterations. Within this paradigm shift, design is understood as a strategic approach -often referred to as 'design thinking' (Brown, 2008)- and as an alternative approach to conventional NPD processes and innovation (Beckman & Barry, 2007; Bessant & Maher, 2009; Bruce & Bessant, 2002; Cross, 2011; Gemsera & Leendersb, 2001; Johansson-Sköldberg et al., 2013; Liedtka, 2015; Martin, 2009; Seidel & Fixson, 2013; Verganti, 2008; Ward et al., 2009). Also, designers are inspired and emerge as a key actors of the team (Perks et al., 2005), addressing users' needs (Chen & Venkatesh, 2013); reinventing business models and NPD processes (Gruber et al., 2015); and bringing unique insights to strategy formation and implementation (Best et al., 2010). Despite limited evidence over how design can be utilised in the NPD process, several studies contributed to identify design practice, issues and skills throughout the process (Beverland, 2005; Goffin & Micheli, 2010; Micheli et al., 2012; Perks et al., 2005).

Design Challenges within Conventional Product Development

Goffin and Micheli (2010) identifies what kind of design challenges the professionals face when integrating industrial design into a structured NPD process. Using the Stage-gate process model, key design issues and potential conflicts throughout each of the stages are described in which a number of functional areas are involved-R&D, marketing, and manufacturing, among many others. The study discovered the two critical barriers to the successful design approaches in NPD teams which are cultural barriers between designers and other functional professionals (Beverland, 2005); and process barriers to combining design practice into NPD (Perks et al., 2005). Although they identified the design issues thoroughly at each stage of NPD process, the study is limited in some respects. Firstly, the issues and conflicts are not covering the most extant of design expertise as none of the companies within the case studies utilised diverse types of design strategy. Although it is reasonable to refer to Stage-gate model as it is most widely used NPD process, it is limited to describing continuous NPD model for IoT products and services.

An ongoing transformation in society, culture and technology has revolutionised the way value is created, and expand the scope of design practice (Buchanan, 1992). Accordingly, the traditional ways of utilising design for value creation and design issues and conflicts over NPD processes is required to be revisited, considering factors that affect emerging design practice and process for IoT development. The factors would include the complex IoT architecture, material properties of connected artefacts, and big data as a resource for designing which lead to distinctive design challenges that organisations and design professionals have to consider. In the next section, existing literature around emerging design practices and issues for IoT NPD will be discussed.

2.2 Emerging Design Considerations Regarding IoT Development

Design professionals have always been aware of the significance of creative design methods within the design process (Churchill, 2012). In particular, they have made great contributions to how qualitative empirical data support to create users' and organisational value through NPD (Speed & Oberlander, 2016). In the digital era, big data is almost entirely quantitative data that has not only been unfamiliar but also been challenging to design professionals as they become more complex, and heterogeneous (Mayer-Schönberger & Cukier, 2013). Although data is regarded as a resource to maintain organisations' design innovation, there is not much evidence on how designers make use of it to improve design (Deutsch, 2015). The advancement of the Internet and the development of IoT interrogate design professionals with a more complex array of data forms (Speed & Oberlander, 2016). As such, the necessities of reframing how designers design around connected artefacts and data have been highlighted. Academics from HCI and design research argue that strategic level of design-often known as design thinking- to be combined with data science process, from data capture, data management to user models and data visualisation and analysis (Churchill, 2012; Deutsch, 2015; Speed & Oberlander, 2016).

Data aware design mindset

One of the critical differences between traditional product development and IoT development is to deal with data practice within the design process. There are several studies on how big data affect value creation and NPD process (Johnson et al., 2017; McAfee & Brynjolfsson, 2012; Yoo, Henfridsson, et al., 2010; Yoo, Lyytinen, et al., 2010), and the frameworks for data-centric design which could be related to the various ways of combining data into design practice or mindset (Deutsch, 2015; King et al., 2017; Speed & Oberlander, 2016). Data-aware design mindset to data process enables to build more user focused system and to achieve meaningful business goals based on active participation of stakeholders (King et al., 2017). With this regard the role of design must play an active role in the mediation of meaningful value across each phase of the data science process (Speed & Oberlander, 2016). Having design decisions involved in the data capturing, analysis, and building data product would effectively solve challenges to users' experience and therefore business (King et al., 2017).

Design as creating meaningful social value

Utilising big data for customised IoT products and services has resulted in an increase of interdisciplinary interests beyond a purely technical perspective (Boyd & Crawford, 2012; Mayer-Schönberger & Cukier, 2013). In particular, ethical issues underpinning concerns of security, privacy and trust are escalated due to the high degree of automation, interconnectivity and processing sensitive private data. Consequently, it leads to considerable scholars' interest on ethical and moral value, and designers increasingly take the role of encouraging user trust (Nickel, 2015). However, literature on trustworthy design is a relatively new topic of which the research landscapes are limited to the functional usability and user interface at the interactional level of the systems (Harte et al., 2014; Lin et al., 2011). Bhattcharya et al. (2017) argue that a trust-based service design approach of which attributes are transaction efficiency, transparency and engagement, and participation and collaboration could relieve the ethical issue and enable better adoption of novel technology.

Design as a medium of decoupling material properties

Embedding microprocessors, memory, communication bandwidth, and power management into non-digital artefacts brings about the distinct characteristics in IoT, for instance, reprogrammability, 3Vs of big data, and heterogeneity. These attributes of IoT make design practices more agile (Svahn & Henfridsson, 2012; Yoo, 2010) as the scope, feature and value proposition of IoT products and services continuously evolve even after being launched and whilst being used (Ng, 2014). Having digital components within the physical products decouples form from function and media from content which brings various opportunities for creating unique products (Jonsson et al., 2009; Tilson et al., 2010; Yoo, 2010). While designers are decoupling form from function, they are able to create new digital properties to IoT products and services (Yoo, 2010) based on their imagination and design decisions on what sensors and software to be embedded, how data could be curated.

In the HCI domain, decoupling material properties could be in relation to the conception of 'affordance' which the term coined by psychologist James Gibson (1977) ‘as the meaning or value of something consists of what it affords’. Later, Don Norman (1988) explains that the role of design is to make affordances easily perceptible to potential users. However, as a single connected artefact could have the convergence of multiple affordances (Yoo et al., 2012), designing IoT with clear affordances could be more difficult than designing conventional products. According to Norman (1988), affordances should be strategically created by designers and in this regard, having emphasis on designers’ imagination could be a solution to create multiple affordances of IoT products and services.

<u>More than Human Centred Design</u>

Coulton et al. (2018) argue that the interrelated collections of objects form IoT constellation which is built on top of Object Oriented Ontology (OOO). OOO is a philosophical theory that positions objects at the centre of being. Tangible objects are what we see as the visible part of the IoT (figure 01 left), but there are invisible elements entangled, such as data, algorithms, networks, and infrastructure, which are often forgotten but exert significant influence in IoT design practice (Figure 01 right)(P. Coulton et al., 2018). Consequently, the scope of product design, i.e., ‘a complete description of the structural elements of a particular artefact’ (Baldwin & Clark, 2000, p.42), not only cover the tangible components of the product, but also the digital materiality and value proposition through data. Moreover, when things communicate to each other and make decisions, only minimum human interventions are required. In this regard, IoT development should be more than human centred design.

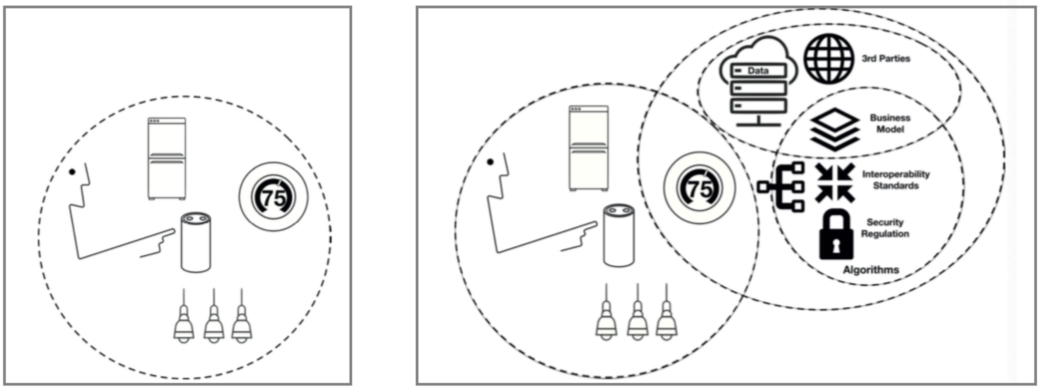

Figure 01 left. Visible things in an IoT enabled smart home system; Figure 01 right. Visible and Invisible things in an IoT enabled smart home system.

3. METHODOLOGY

This study is based on an inductive approach under the constructivism as it aims to understand IoT design and development. Thus, the research study currently involves qualitative research methods as it is widely acknowledged that qualitative research produce comprehensive understanding of rich, unstructured and contextual data in a natural setting (Creswell, 2009). In particular, an extensive examination of current literatures, multiple case study and thematic analysis method are adopted to answer the research questions. The first author undertook both data collection and the data analysis. More detailed outline of research design is described as follows.

As part of literature review, books, articles and academic texts were broadly selected, searching through electronic databases such as Springer Journals Archive, Wiley Online Library Journals, and ProQuest Business Premium Collection. For comprehensive understanding on the existing literature on design, search terms used, include 1) “design”, “role of designer”, “design contributions”, “design challenges”, and “strategic design”, 2) “IoT design”, “trustworthy design”, “data-enabled design” and, “more than human centred design”. Each text was critically examined for their relevance to the primary question(s) of the main research study.

A case study methodology is regarded as an appropriate research strategy because it defines topics broadly not narrowly, cover contextual conditions and not just phenomenon of study, and rely on multiple and not just singular sources of evidence’ (Yin, 2003, p. 33). There is a lack of existing research on how IoT products and services are designed and developed, and what are the challenges and changing role of design within the process. Thus, the current study investigation adopts an exploratory multiple case study to gain a primary understanding of IoT design and development (Yin, 2003, p. 3). The units of analysis for the case studies is IoT development project rather than at a firm level. Through the semi-structured interview, distinctive experience and design challenges can be interpreted by each participant within the context of the given project, which informs a holistic understanding of IoT design and development. As a supplementary means of gathering data, different sources of electronic documents were obtained, including news articles, press releases, posts on SNS platforms, portfolio, the user forums’ website and so forth. These were specifically useful when the events were no longer be observed or informants have forgotten the details (Bowen, 2009).

The author adopted criterion-based case sampling with which data quality is assured, having all cases met the predetermined criterion of significance (Patton, 2014). The following criteria were considered for case sampling: a) The project should aim at developing a new IoT product and service (or products and services); b) The IoT product and service must be launched to the market to investigate design challenges over the whole NPD process; and c) The geographical location of the IoT project should be based in the UK for the reason of the accessibility and resources. Thirty-one companies were initially identified and invited to participate in the case study via email from January to April 2018. Considering the recommendations and the balance between theoretical saturation and practical constraints (Eisenhardt, 1989), six cases were selected including one pilot study conducted in 2018. The selected cases were varied in terms of project period, type of organisations, market segment, and the form of commercial transactions (Table 01).

In essence, one interview per case was undertaken as the sources of empirical evidence from the experts with strategic- and operations- level knowledge and experience in IoT development. Exceptionally, in the case of highway maintenance IoT, two interviews were carried out because the managing director advised to conduct the supplementary interview with the project manager to avoid the lack of evidence in profound operations-level knowledge and experience. An in-depth semi-structured interview as the primary data source for the study was undertaken over a three-month period between 21st February and 4th April 2019. All interviews were one-to-one sessions ranging from approximately one to two hours in length, with an average of 1 hour 15 minutes at the informants’ preferred space. The interviews were recorded upon the consent of the interviewees and transcribed by the researcher for later coding. Coding of the early interviews was conducted alongside the later interviews was undertaken.

To complement and triangulate the evidence provided by the informants, different source of electronic documents was collected before and after the interviews. In total, 188 distinctive electronic documents and video clips were obtained most of which were qualitative and descriptive data covering design and development activities and business events within the development period of each case. Internal archival records were not obtained in this study for different reasons, including the project confidentiality, nonexistence of the documents, and the informants' furlough due to Covid-19 travel restrictions. In the document reviews, rigorous, systematic and transparent approach (Higgins & Green, 2008) was adopted in the following steps: 1. Obtaining all materials which help to understand design practice in IoT development; 2. Extracting relevant data; 3. Analysing data, and 4. Synthesising data.

Thematic analysis was adopted for this study as it is suitable for a purely qualitative, rich, detailed yet complex, account of data analysis (Braun & Clarke, 2006) and identification of common threads which spread out across a single interview or set of interviews (Desantis & Ugarriza, 2000). Thus, the transcribed interview script contents and obtained documents for all the cases were carefully analysed through within- and cross-case analysis strategies (Eisenhardt, 1989), using thematic analysis (Braun & Clarke, 2006; Vaismoradi et al., 2013). Firstly, the recorded interview was manually transcribed through denaturalistic transcription style in which 'idiosyncratic elements of speech (e.g., stutters, pauses, nonverbal, involuntary vocalisations) were removed' (Oliver et al., 2005). Then initial codes, categories and themes from the data in each case were generated and iteratively refined under an inductive approach. Along with within-case analysis, cross-case analysis was carried to recognise emerging patterns across the six case studies.

Regardless of the philosophical stance and research approach, a research should be designed and implemented to convey trustworthy answers to the question in a credible and justified manner (Jaakkola, 2020). To enhance the study trustworthiness, triangulation of multiple data sources, member checks, and peer reviews were drawn upon. For the member checks, the interpretations of the data are shared through email in which the conversation and opportunities to discuss and clarify any omitted or inaccurate information. The peer review was carried out by peer reviewers of a couple of conferences and journals (Lee et al., 2019a, 2020, 2019b).

4. EMPIRICAL DATA

For the research, six cases were investigated, which is described below in Table 00. The project period varies, the earliest project started in 2003, and the latest one started in 2015. Apart from Case A, all the cases aim to commercialise both B2C or B2B market and start-ups as private companies or private VC-funded companies. The market segment is diverse from healthcare, home, drain management, dairy, vertical farming and tropical agriculture. All the companies who led the project own the hardware and software of IoT, but only A, C, and D have embedded machine learning and data algorithms in their system. Apart from Case D, who never worked with designers, Case B, C and E have worked with external design consultancies, whereas Case A and F have had an internal designer or a design researcher.

Categories	*Case A*	*Case B*	*Case C*	*Case D*	*Case E*	*Case F*
Project period	2013-2018	2006-2015	2011-present	2003-2016	2015-present	2015-present
Form of Commercial Transactions	Not aim to commercialise	B2C	B2B	B2B	B2B	B2B
Type of organisations who led IoT project	*A University*	A Private VC-funded company	A private company	A Private VC-funded company	A Private VC-funded company	A private company
Market Segment	*Healthcare*	Home	Drain maintenance	Dairy	Vertical Farming	Tropical agriculture
IoT products and services	A wearable device, a charging pad, up to 30 sensors and an application	A smart hub with a number of securities, safety, energy products and services	IoT hub including sensor network, data models, and decision support system	Smart neck mounted collar and system	Vertical farming hardware and software system	Weather station, the analytical software and the application
Value delivered through IoT systems	Measuring cost of acquiring data	Improving energy efficiency, security and safety	Reducing costs and improve efficiency in gully and drainage management	Increasing animal's fertility & improving animal's health	Tracing crops from seed to sale, making operations more efficient	Enabling the farmers to implement the right practices
Use of AI	Yes	No	Yes	Yes	No	No
Design Contributions	Internal Designers	External Designers	External Designers	No Designers	External Designers	Internal Designers

Table 01. Profile of six IoT development cases

4.1 Case A (SPHERE)

Project overview

This project is a smart home system for monitoring inhabitants' physical and mental wellbeing. Funded by the EPSRC from 2013 to 2018, Bristol University led the project in addition to project partners from other academic institutions, industry, local government, and other stakeholders. As the project did not aim to commercialise the product but to understand the value and cost of acquiring data, findings from this case would possibly be limited.

Design contributions

The team placed strong emphasis on design input in identifying users' needs and testing feasibility and acceptability. When identifying customers' requirements, a series of workshops and meetings were organised, of which the format was based around conversation and brainstorming ideas. Feasibility and acceptability were tested through a combination of traditional ethnographic methods and participatory techniques. The team built the physical space where all the sensors deployed in order to monitor how users were used and perceived the systems.

Design challenges

The risk of identifying customers' requirements stage is that customers generally are not trained to articulate and define their requirements. Although they identify their requirements, it could be impossible, contradictory or poorly defined. Critical questions were raised, including what kind of system to develop whether the system would be reliant on AI, and whether to use labelled data. Another technical issue was not knowing system performance until the system was developed and deployed. The sensor prototype and development stage must follow quickly to understand if the right decisions have been made. The small sample size was insufficient to make decisions and a consensus when testing feasibility, and acceptability.

To test and evaluate the system thoroughly without completing the product and service ecosystems was incredibly challenging. Developing digital artefacts challenged the designer with a continual pressure of never fixing the design and integrating the system. Integrating IoT systems were highly complex and often required strategic alliances with device manufacturers, software developers, or service providers. Special attention to issues around quality control should be paid during the procurement phase of the IoT development. Particularly, being unable to procure hardware components could lead to the whole system being re-designed again, new suppliers found, or the design was changed.

4.2 Case B (AlertMe)

Project overview

The team aimed to develop an IoT hub that improves energy efficiency, security and safety at home. Safety and security service was launched first in England in January 2007; then, it took two years to extend the energy service. For nine years of IoT development until before an energy provider acquired them, they have worked with diverse actors and partners to create and scale up a platform for the smart home, such as security, energy and telecare.

Design contributions

There were no in-house designers at the beginning of the project. However, the customer service team happened to have a user-centred mindset, as they allocated a significant amount of time and efforts at customers' houses to fix the technical problems. They conducted a series of survey and ethnographic research to understand how IoT products and services were used in customers' house and to identify future value propositions. In addition, having partnerships with external design consultancies enabled improving packaging design and developing various product ranges more user-centred.

Design challenges

One of the critical activities was to achieve the technical architecture right and pull all different IoT architecture layers together, considering the possibility of scaling up the system in the future. There was often tension between security and usability issues. If the IoT system is designed to be secure, it was challenging to use. Managing supply chain and quality control was hard at the manufacturing stage because most IoT components were manufactured at relatively low volumes, often leading to component shortages. Therefore, it resulted in the team redesigning the whole IoT hardware and software.

The primary risk of marketing, launching, and sales were cash flow and considerable allocation of market engagement resources. Since the IoT devices were self-installed, the team had to design them easy to install, which led the team to improve the IoT system deployment more straightforward and easier continuously. While IoT systems were deployed and used, many issues were found, including data and system accuracy, data security, privacy, and trust.

4.3 Case C (InTouch)

Project overview

This IoT development aims to reduce costs and improve gully and drainage management efficiency, informing of when it should be cleaned and inspected with the live data. IoT system, including the IoT sensor network, data models, and decision support system, the system for drain maintenance was first applied to highways then extended to national railways. As part of the product offering with other stakeholders, the team created value by applying several different data factors to the predictive model to distil insights and satisfy business needs.

Design contributions

Users and stakeholders were involved in the whole process to identify business needs, what value to create, and how to create value. With the user-driven innovation mindset, the company held innovation workshops, liaised with customers regularly, aimed to understand government policy and the future technology to formulate solutions to move the solution forward. During the feasibility study phase, repetitive ethnography research was conducted with the partner University to understand how they could effectively operate the original gully emptying system.

Design challenges

Having no economic driver to make data meaningful was a critical issue, as it would cost a considerable amount of money. The acceptability and adoption of the IoT system to their existing customers was significant not to lose their existing customers. It was challenging to customise services, depending on the diverse needs of different future customers. Securing funding was critical to direct the traditional business model to an IoT business. Due to the complicated value constellation, inherent risks were associated with the competitiveness between the team and the business partner, and design subcontractor.

Having requirements identification was a challenging process because each stakeholder had different opinions depending on their interests, such as the product lifetime guarantee and product life span. The lack of knowledge concerning designing and prototyping hardware was a significant risk for the team as no one could manage the product's quality developed by the design subcontractor. Designing the system with a user-friendly front-end interface, letting users choose the kind, the level, and the amount of data they want to see was another hurdle. There was conflict between getting something to market quickly and trailing it against the fact that it is full of technical failures and falls over. The system's integration was one of the most significant challenges.

Validating data and building trust with end-users over the trial stage was considerably challenging. At the monitor, maintain and curate data stage, the team continuously tried to increase its overall accuracy. Data security, privacy, ethics, and trust were always significant to the highways customers and the team. Transforming data into economic value by sharing and curating it with customers was again, challenging. System maintenance and commitment were closely related to data reliability, availability, storage and standardisation. For example, some data has to be stored for 20-25 years, but the maintenance cost of storing data and running the system could be a large burden for SMEs. Scaling up the business requires the development of IoT system properly from beginning, which could pose a considerable risk.

4.4 Case D (SilentHerdsman)

Project overview

This IoT system targeting dairy market has been developed from 2003 to 2016 to satisfy the increasing worldwide demand for good quality animal products in combination with responsible farming. Animal’s fertility and health is continually monitored through the neck-mounted collar by detecting its eating behaviour, heat expression, and rumination 24/7. The value of the IoT system is to provide automatic indication of the animals eating behaviour, heat expression, and rumination to the farmers, which would then support their decision-making on the optimum intervention.

Design contributions

The market needs were identified and validated within the market foresighting stage through a series of consultations with the sector supply chain, such as farmers, herdsman, main retailers, logistics, milk recorders, artificial inseminators, nutritionists, animal scientists, and technology providers. It was fundamental to 'listen to your customers' during the entire IoT NPD process but specifically at the stage of understanding current on-farm practices, in turn informing what and how data should be presented, core to all IoT successful operating systems.

Design challenges

In the development of the solution and managing the input from industry stakeholders, critical decisions were reached such as; what is the minimum viable feature set of the product?; what is the form factor?; what is the products' lifetime requirements?; the definition of the deployment process?; and what is the overhead in terms of the maintenance cost? The stages of developing the initial algorithm, testing and validating the accuracy of algorithms, and refining algorithms was time intensive and resource consuming. Having access to on-farm environments to deploy and test the neck-mounted collar was critical to the overall success of the project.

The phase of developing, testing, validating and refining algorithm was a long and challenging journey. Apart from time and financial issues, the team encountered a series of development risks such as the performance of the IoT system; the risk of misunderstanding the appropriate market segment; the risk of not having algorithms(s) which are fit for purpose; and the risk of limited market traction. Securing funding was also a significant issue to ensure that the team generated sufficient on-farm data to validate the algorithms. To commercialise the concept, the Return of Investment (RoI) of the system had to be accurately validated. Drawing market attraction was a major challenge as the dairy farming had followed many years of established standard practices, which were difficult to quickly change.

4.5 Case E (LettUsGrow)

Project overview

The project is targeting B2B vertical farming initiated by three co-founders in 2015. The IoT system integrates vertical farming hardware, sensory data, software system, and access to network-sourced data optimisation. The software automates and controls the entire indoor growing system, whilst collecting data on plants, overseeing inputs to crop growth and allowing farmers to trace crops from seed to sale, making operations more efficient.

Design contributions

In this project, design contribution to IoT development was mainly related to two perspectives. Firstly, focusing on a human-centred design approach, design played a significant role in encouraging the team to work with growers (in-house and external), biologists, and end customers, which was critical to understanding the complex multivariable system that is growing plants as a business. Second, design intervention also reconfigured the existing NPD process with more rigour and afforded the team a competitive advantage.

Design challenges

At the R&D stage, ideas should be transformed into the right product in a short space of time. The feasibility was hardly identifiable unless it was physically built, integrated, and rigorously tested. While identifying technical specifications, the small number of customer samples possibly affected key decisions, particularly bias and specificity, not reflective of the entire industry. One of the main risks in prototyping was a conflict between making enough prototypes and the cost of source materials. Thus, the team had to ensure that they had control over the financial issues. At the system and subsystem verification stage, the most significant technical risk was unexpected interactions, emergent behaviour or the system not working as expected.

The different software and hardware development pace were critical, as technical faults on the hardware side took longer to find than the software side, as it needs to be tested nightly to discover if it breaks. The investor prototype aims to convince investors to secure funding. However, the team were unsure if it was ready to get investment or represented the final product. When supporting the after-sales service, the twenty-year maintenance contract is an issue since it has never run for twenty years. It was completely unknown whether the solution would last twenty years.

4.6 Case F (ClimateEdge)

Project overview

The two co-founders started the IoT development with an environmental technology background in 2015, intending to create a tailored system to support smallholder farmers and cooperatives in crop agriculture, including coffee, cacao, tea, and bananas. The IoT system consists of the weather station, the analytical software and the application.

Design contributions

The team had an internal designer from the early stage of the NPD process. The most crucial design role was to understand the users and create a user-friendly system reflecting their needs. A user-centred approach was the key in the NPD process by providing consulting service to farmers and cooperatives. The weather station was designed and iterated based on extensive user testing. The software excels in presenting data in an engaging and easy to understand format.

Design challenges

Problem identification is an ongoing activity throughout the whole NPD process. The team had to parameterise problems because the clients were often unaware of what they were struggling with and what they wanted. The issues were often related to the symptoms rather than the causes. At the proof of concept, manual data collection on air and soil temperature by sensors was a tedious and time-consuming process. Once the MVP (Minimum Viable Product) was ready, the working prototype was offered to the farms to test the concept and obtain feedback on both software and hardware. However, the MVP was not good enough to explain and make people comprehend what a solution looks like and how it works, so that it was difficult to secure feedback on the system and UI framework.

The critical issues in testing the weather station's design were to make it more user-friendly, well thought through and to withstand tropical weather conditions while being cost-efficient and easy to service and upgrade. Accessibility was a key priority in IoT development. As each region and the individual farmer had different needs and requirements, the different feeding information methods back to the farmers within the application were developed, including web, app, SMS, and voicemail. The risks at the production, deployment and providing service stage were mainly related to cash flow.

5. FINDINGS AND DISCUSSIONS

5.1 Design Contributions

Through a thorough cross-case comparative analysis, different stances of design, positivistic, constructive and pragmatic, are observed in the course of the iterative NPD process. At the earlier cycle of NPD process in which there is no formal structured NPD process, design activities tend to be 'black-box' (Fallman, 2003), focusing on framing wicked problems (H. Rittel, 1972). On the contrary, after the IoT system is deployed design activities are considered more of a scientific process (Cross, 2001), preparing the products for scaling and tooling up the batch production. Regardless of the phases of NPD process, design for IoT is regarded as an augmentative process (Rittel & Webber, 1973), making sense of complicated value constellation(s) and IoT architecture.

The certain patterns of design contributions are identified as follows:

1) Despite an absence of internal designers, a co-design approach was applied and appreciated from the beginning of the NPD process;

2) When working with external designers, companies are likely to restrict designers' involvement to the early and late stages of the NPD process; and

3) Regardless of digital data availability, established design practices and methods, including ethnographic research, workshops, interviews and surveys, are still the major activities deployed to understand users and mediate value creation.

<u>Design approaches as culture</u>

Firstly, design has permeated in IoT NPD processes as more of culture, including a co-design approach, or user-driven mindset. Despite no in-house designers, different personnel who closely work with customers have a user-centred mindset, including engineers and/or customer service employees. However, it sometimes requires training to have a design thinking perspective. A user-driven orientation is considered in valuable not only to understand users' and diverse business actors' needs to interpret the right solution within complex value constellation but also to have a good relationship with future customers to collect data and test the IoT system algorithm prior to launching.

> *"Educating the engineer about this is how you talk to a customer, don't use jargon, don't use acronyms, use some visualisations to explain. Because any customer when they meet someone from technology normally customer doesn't understand the technology and the technology person doesn't understand customer."_Case A*
> *"We are always trying to have end user as a partner. So, in this first round, that's exactly what we did with Bristol, as a council and they agreed to trial the system and see what benefits we could get out of it."_Case C*
> *"We worked with the farmers, supply chain, herdsmen, scientists, the market tiers. Supply chain includes all the suppliers related the milk to the supermarket."_Case D*

<u>Absence of strategic level of design</u>

Secondly, in cases B and C, companies are likely to limit designers' involvement to the early and late stages of the NPD process. In case B, a couple of design consultancies contributed to packaging design and improving the hardware side of IoT. Similarly, in the case of C, the company subcontracted a design company for hardware design and development. This is not much different to traditional design contributions, where designers are focussing on the functional aspects of product development and branding (Perks et al., 2005). Exceptionally in case E, the strategic level of design was applied to the project through a InnovateUK funded project. Having an opportunity to work with a design consultancy, reinventing value propositions by bringing unique insights to strategy formation and implementation (Best et al., 2010) and reconfiguring NPD processes (Gruber et al., 2015) was achieved.

> *"We got to design with InnovateUK design foundation last year. That was all around during initial research, which we spent a lot of time then collecting, doing market analysis, etc. This project gave us the space to look at the design process by going out and talking to future users and understanding what their needs are."_Case E*

Established design methods for identifying users' needs

Regardless of available digital data collected from the IoT system, all organisations value and adopt established design practice and methods to understand users and mediate value. Including ethnography, interview, workshops and ethnographic survey, existing qualitative data practices were more easily used than data science practices. In addition, designers were involved in data practice, but it was also provided by software engineers or data scientists. Although scholars highlight the significance of the strategic level of design applications to and emerging practices for data practices (Deutsch, 2015; King et al., 2017; Speed & Oberlander, 2016), it is found that the industry may not be ready for the paradigm shift.

> *"The method here is just a meeting but you need something like brainstorming or conversation but it just takes very long time to do very well"_Case A*
> *"So, when we had a couple of hundred B2C customers, we spent a lot of time going out and talking to them, running ethnographic surveys, understanding what they cared about in their house. We sometimes have to go out because we're having to fix the technical problems."_Case B*
> *"We hold innovation workshops; we speak to our customers on the regular basis. We did lots of ethnography reports with the University where we went into industry to understand how they did the work"Case C*
> *"We have spoken to all of the farms in the UK, all of the vertical farms to different levels. So, in terms of informal conversation_Case E*
> *"In often that there are a lot of conversations with the clients, and with the customers because you are coming from the separate point of viewing and understanding,"_Case F*

5.2 Design Challenges

From the multiple case studies, a diverse variety of design challenges was identified. Some of the risks were general issues that start-ups or high-tech companies often encountered, including financial issues or lack of human resources. However, other risks were distinctive, specifically related to the development of digitally interconnected products. At the early phases of the NPD process, the development risks were more concerning technical issues, whereas the latter phases mainly concerned management related issues. The biggest challenges were likely that the same as most of the other start-ups; making sure that what they commit to the building is correct, growing the business efficiently but also as efficiently as possible, and making sure it was financially viable to develop the system. It required a delicate balance between allocating enough time on validating product-market fit versus financial fundraising. It was particularly critical, but when being given only a certain amount of time and a small team, it is required to make decisions on what is most important at that moment in time.

A complete novel product

Identifying customers' requirements as well as obtaining feedback on the IoT, system is challenging. This is not only because they generally are not trained to articulate and define their needs, but also unfamiliar with a complete novel product, not knowing the opportunities and benefits they could achieve from it. Moreover, unless the system is fully developed and the users can use the system, it is difficult to obtain sufficient insight into how the users interact with the system. This is related to the fact that IoT is an entirely new technology with the convergence of the digital and the physical worlds. Designers have played a critical role in addressing users' needs (Chen & Venkatesh, 2013) and refining, discovering design possibilities through prototypes (Lim & Stolterman, 2008) in the traditional NPD process. However, due to emerging technologies being conceptual in nature, strong design contribution are required, making the concept more tangible and decoupling material properties (Yoo et al., 2012). Alternatively, in HCI, Prototypes are recommended to be used in participatory innovation, which helps different actors experience a possible future and link between analysis and design (Boer & Donovan, 2012).

> *"Like I said, customer cannot really articulate their requirement. It is not right for customer to say I know, and I need this."_Case A*
> *"It's very hard to get feedback on something that doesn't exist from users. You can't be like "I want you to imagine sending a text to a thousand farmers. What worked" and you would be like imagining something there. It doesn't make any sense"_Case F*

Complex IoT architecture and value constellation

In terms of having the right solution, the vision of the system is clear. However, when considering numerous individual parts to achieve the aim, it is never straight forward due to the system's complexity and complexity. This issue commonly occurs when integrating complex systems. When merging hardware, software and data algorithms, unexpected technical issues usually occur, which could take a day or a year to resolve. In addition, when the system has to be integrated with other devices or systems, it could be another critical design challenge, often requiring strategic alliances with device manufacturers, software developers, or service providers. Design could contribute to this by being more agile in experimenting and learning by doing (Boland & Collopy, 2004; Holloway, 2009).

> *"There is always the risk that every system that you've built into design doesn't actually do what you intended at this stage. So, we, sometimes on subsystem level, go around this loop (to the prototyping) a couple of times if there are any mistakes, etc the prototyping."_Case E*

Complicated value constellation of IoT system could cause inherent risks of competitiveness, and responsibility specifically when data is leaked. The more complex value constellation means the bigger possibilities of value creation are expected as well as more considerable risks exist (Speed et al., 2019). This could be closely related to quality control at the procurement and manufacturing stages of the NPD process. If one component is no longer available, the whole system could have to be started again with design changes. In line with Coulton et al. (2018), the authors argue design should be more than human-centred design but consider invisible elements of IoT system, including infrastructure, value proposition and constellation.

> *"The systems spread around the different stakeholders. Everything needs to be procured, tested, assembled, configured, software installed, and even you have to talk together which is actually really hard to do that within one an organisation."_Case A*
> *"There is no one piece of rocket science you have to get right, there's hundreds of things you have to do really well. And if you get any one of them wrong, the user experience will be bad. So, that's the biggest challenge actually sort of complexity."_Case B*
> *"We currently find ourselves working a lot with other infrastructure providers, so people who already have communications networks out there and we're trying to form strategic partnerships with them. However, this inherently comes with risks associated with the competitiveness."_Case C*

Acceptability, adoption, trust, privacy and security

Adoption, acceptability, trust, privacy and security are key priorities for value creation, interrelated to each other. For example, adoption and acceptability of the

IoT products, different factors have to be considered at the initial design stages, including making the system user-friendly, making self-installation easier, demonstrating RoI, and building trust by providing accurate and reliable information. As discussed earlier, designers have to consider the invisible parts of the IoT system. However, whether complex or not, the invisible part of IoT system is (P. Coulton et al., 2018), the visible part of IoT system may need to be designed user-friendly. Moreover, designers have to contribute to the communication of how IoT system would value customers intuitively and vividly.

> *"We are working on different methods of feeding back information to the farmers. We have developed web software, but we know that not all farmers will have access to computers or smartphones, so we're also making use of SMS and voicemail."_Case F*
> *"Because farmers are entrenched practices. They did their own ways for over 100 years. You need to demonstrate Return on Investment and convince them."_Case D*
> *"If people don't trust information, if the information is not readily available, if the information is false, then people won't use it."_Case C*
> *"The other thing is like new security, vulnerabilities, so even if you are happy with your hardware, suddenly you find something threat to the system. And then, you have to change your processor or change your software or something."_Case A*

Although there are significant design challenges that are identified within IoT NPD processes, and design scholars propose novel design approaches to critical these challenges, design contributions towards IoT development are reasonably limited. As design scholars argue, designers may need to adopt a proactive and novel approach to creating meaningful value within IoT development activities.

6. CONCLUSIONS

This paper offers initial results of current doctoral research, based on a comprehensive literature review and multiple case study analysis. It concludes by offering key insights and implications on how design and development practices for IoT products and services could be reframed. The authors argue that the research study has some significant contributions to the advancement of the field of IoT design. For academics, the research project contributes to augmenting the body of literature regarding emerging design process for IoT and can serve as a starting point of future in-depth research on IoT design. For practitioners, the research study would help design industry professionals to understand how design could contribute towards meaningful value creation. When a company decides to apply IoT technology into a specific proposition, this study serves as a framework to guide as to how IoT products and services could be designed and implemented.

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