# The User Experience Perspective of Internet of Things Development

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MASTER'S THESIS

# The User Experience Perspective of Internet of Things Development


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## Abstract

In current research of Internet of Things (IoT), there is limited research on the user perspective and even less on how companies operating in the field consider User Experience (UX) when developing for IoT. The aim of this thesis is to investigate how UX is considered during the development process of IoT. It also includes exploring to which extent this is done with a data-driven approach. The study includes a literature review and an empirical study. In the empirical study, eleven companies operating within IoT have been interviewed. Even though that it is difficult, based on our results, to distinguish IoT-specific characteristics in the development process, the combination of hardware and software appears to be specifically challenging in the context of IoT. When it comes to data-driven development, it was shown that when the companies collect quantitative data, it is preferred to complement it with qualitative data in order to evaluate and improve the UX of a system. Finally, *communication*, *finding the value in connecting things*, *interaction*, and *privacy and security* have been identified as UX challenges in the context of IoT.



**Keywords**: User Experience, Internet of Things, data-driven, development process

**Sammanfattning**

Inom nuvarande forskning om Internet of Things (IoT) finns det inte många studier som har tittat på användarperspektivet eller på hur företag som är verksamma inom IoT avväger användarupplevelse när de utvecklar IoT-produkter. Syftet med denna studie är att undersöka hur användarupplevelsen tas hänsyn till under utvecklingsprocessen för IoT. Den syftar också till att undersöka i vilken utsträckning detta görs på ett datadrivet sätt. Studien inkluderar en litteraturstudie och en empirisk studie. I den empiriska studien har representanter från elva företag som utvecklar IoT-produkter intervjuats. Trots att det är svårt att, baserat på våra resultat, urskilja om det finns några IoT-specifika kännetecken i utvecklingsprocesserna, verkar kombination av hårdvaru- och mjukvaruutveckling vara särskilt utmanande inom IoT. När det gäller datadriven utveckling, visade det sig att företagen som samlar in kvantitativ data också kombinerar det med kvalitativ data för att utvärdera och förbättra användarupplevelsen av ett system. Slutligen har *kommunikation*, *hitta värdet i att koppla upp saker*, *interaktion* och *säkerhet och dataintegritet* identifierats som utmaningar i sammanhanget av användarupplevelsen av IoT.

**Nyckelord**: Användarupplevelse, Sakernas Internet, Internet of Things, datadriven, utvecklingsprocess

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# Chapter 1
# Introduction

The concept of Internet of Things (IoT) has received extensive attention during the last couple of years. IoT is presented by the EU as *"the next step towards the digitisation of our society and economy"* [1]. The EU programme Horizon 2020 includes providing support and investment in IoT research and innovation objectives. Along with the new possibilities that comes with IoT, there are also technical challenges that need to be addressed.

With the prediction that IoT will transform our society by interconnecting people and things, it is evident that the people will be as much a part of IoT as the things. While the technology behind the things is in focus within the research, there has, to our knowledge, not been as many studies conducted which consider the human part of the IoT. A constantly connected society is, by the means of smartphones, already a reality. But how are people affected by an increasing presence of IoT? How do people experience IoT? Moreover, does the industry, which stands for a large part of the innovation, take the User Experience (UX) into consideration during their development process?

IoT enables processing and sharing of data to a degree that previously has not been possible. In digital applications, it has become increasingly common to use such collections of data to reveal information about how the users' behaviour and preferences when interacting with the application. In other words, it is an attempt to measure the UX [2]. Thus, can the data aid in answering the question of how people experience IoT?

The literature review performed in this thesis shows that there is limited research on the UX perspective of IoT and how this affects the development process. Consequently, there is even less research performed on if and how a data-driven approach towards developing IoT with a UX-perspective is applied within the industry. The aim of this thesis is to explore this area. Therefore, we formulated the three research questions displayed in Table 1.1.

In order to explore the answer to the research questions, we have performed a literature review as well as an exploratory case study with practitioners from eleven Swedish companies that develop IoT.

The background of the thesis is elaborated in "Chapter 2. Background". It provides an overview of the two main topics that are covered - UX and IoT. In "Chapter 3. Literature

**Table 1.1:** The research questions

| | |
|---|---|
| RQ1 | *How is UX taken into consideration during the development process of IoT?* |
| RQ2 | *How is data-driven development from a UX perspective applied within IoT?* |
| RQ3 | *Are there any specific UX challenges that need to be considered during the development process for IoT?* |

Review", the method and the results from the literature review are presented. Accordingly, "Chapter 4. Empirical Study" consists of the description of the method, the participating companies, and the results of the empirical study. Finally, in "Chapter 5. Discussion" and "Chapter 6. Conclusions", the main findings from the literature review and the empirical study are discussed and concluded.

# Chapter 2
# Background

This chapter will cover the two main topics for this thesis; User Experience (UX) and Internet of Things (IoT). Each topic will be dealt with in one separate section.

## 2.1 User Experience (UX)

When a system is developed, a user experience is simultaneously created. A user experience cannot be designed, but it can be an aim to design *for* a user experience [3].

As described by Arvola [4], the design process became in the beginning of the 1990s increasingly focused on creating rich experiences. This resulted in that the design process was refined into including not only usability requirements, but also user experience (UX) goals. In the international standard ISO 9241-210, "Ergonomics of human-system interaction", UX is defined as *"a person's perceptions and responses that result from the use or anticipated use of a product, system or service"* [5].

In this section, UX and related terms are outlined in order to place UX in the context of software engineering processes. In section "2.1.1 Related Concepts", the concept of quality requirements is described, before narrowing down the perspective to usability. Due to the difficulty in separating usability and UX, UX is defined by comparing it with usability. The concept of Quality of Experience (QoE) is also discussed. Subsequently in section "2.1.2 UX Design", a description of the UX design process is made. Special considerations have to be taken regarding UX and the integration of the UX design process when applying different software development methods, which is discussed in section "2.1.3 UX and Software Engineering Processes" and section "2.1.4 Data-driven development and UX".

### 2.1.1 Related Concepts

Lausen [6], clarifies the distinction that is made between functional and quality requirements within software engineering. As the term indicates, functional requirements express what functions a certain system is to perform. The quality requirements, or non-functional requirements, specify how well a system must perform its functions. These requirements are described in ISO 25010 [7]. They can be specified both as software requirements as well as requirements for the entire system. Depending on the character of the quality requirement, the requirement can depend on hardware, software, management, and physical factors.

One of the eight quality requirements in ISO 25010 is *usability* [7]. Usability is defined as *"The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use"* [5]. The UX and usability pioneer Donald A. Norman and Jakob Nielsen, who is the co-founder of their consulting company, distinguish UX from usability by referring to that usability is a quality attribute of the user interface (UI), whereas UX extends beyond that and concerns every part of the system [8]. They complement the ISO definition of UX as including *"... all aspects of the end-user's interaction with the company, its services, and its products"*. This complies with the elaboration of the concept that is made by Preece et al. in [3]. It is stated that UX is about how the users feel about a system and their pleasure and satisfaction that they experience in all different situations that involves any kind of interaction with it. Consequently, the UX goals are more subjective qualities of the system than the usability requirements and cover desirable and undesirable emotions and experiences that the system is to induce. Such qualities can be abstract words, such as "engaging", "supporting creativity" and "rewarding". Therefore, it is, according to Garrett [9], not enough to consider only the aesthetic and the functional design for the UX of a system to be satisfying. The aesthetic and functional aspects of a certain part is aimed to work in the context of the rest of the system.

With the extension of the notion of usability into UX, it becomes more difficult to distinguish UX from other related concepts, such as *interaction* and *Quality of Experience (QoE)*. Interaction is a component of creating UX. The interaction design discipline revolves around choreographing the interaction while UX design extends further into including the experience that any type of interaction creates for the user [10]. However, interaction design is applied with the aim of designing for UX, and the distinction is therefore not easily made. QoE and UX are even more complicated to separate. The QoE is a concept that provides an even more holistic approach, since QoE includes UX as well as three additional attributes: the communication situation, service prescription, and technical parameters [11]. These attributes can be incorporated in the term Quality of Service (QoS), which, as depicted in [11], includes measuring technical characteristics that affect the service performance.

### 2.1.2 UX Design

Hartson and Pyla [12] describe the UX design process as usually consisting of four phases; analyse, design, prototype, and evaluate. As can be seen in Figure 2.1, the process is highly iterative, where the different phases are iterated along the way. A short description of each phase is provided in this section, based on the descriptions by Preece et al. [3], Arvola [4], and Hartson and Pyla [12].

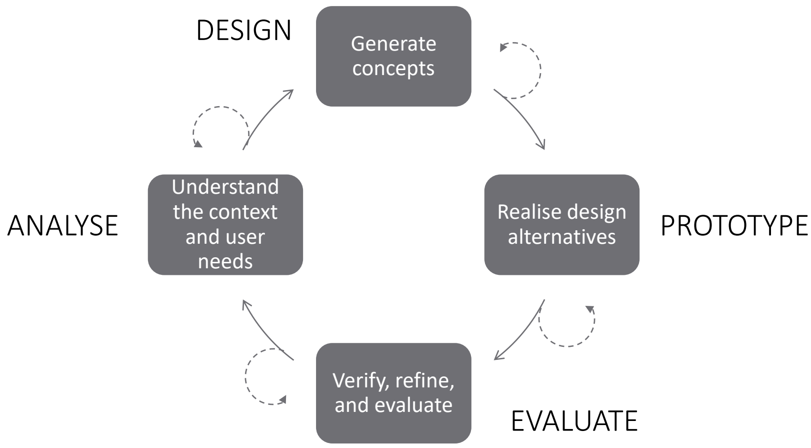


**Figure 2.1:** Illustration of the UX design process

## Analysis

The analysis phase consists of performing *user research* and *contextual research*. These comprise different kinds of data gathering activities, where the three most common ones are interviews, questionnaires, and observations. Other techniques, such as focus groups, studying documentation, and researching similar products, can also be applied. The aim with the collected data is to learn about the users and their needs, while also extending to exploring the context in which the users and the future system will reside and interact [3] [12].

There are different techniques that can aid in extracting results from the relatively unstructured data. Often an affinity diagram is used to categorise the data, and the resulting insights can be described with the means of personas, scenarios, and use cases [3] [4]. The results from the user research can be used to establish requirements [3].

## Design

The design phase constitutes specific activities which aim to assist in the designing of alternatives. This involves creating a conceptual model for the product or system, and developing a concrete design. These two concepts are relatively intertwined and the shorter the design cycle, the less is the distinction between them. With the conceptual design, the requirements are transformed into a conceptual model, which outlines what the users is to be able to do with the product and the concepts that must be understood in order to interact with it. The concrete design concerns the visual appearance and the application of design principles, as well as addressing issues related to user characteristics and context [3].

### Prototype

The conceptual and concrete design can be illustrated and supported by different, simple techniques, such as sketching and storyboarding. When the system is sufficiently defined for moving on to the next phase - prototyping - those activities can also be applied in the context of low-fidelity prototyping. Such prototypes are not developed with the main aim to resemble the final product, but to explore alternative designs and ideas in an efficient and inexpensive way. Thereafter, the resulting design and concept can become more and more detailed and thereby shifting towards a high-fidelity prototype. With this, more functionality is provided, thus enabling testing of technical issues and selling ideas [3].

### Evaluate

The last phase of the iterative design cycle consists of evaluating the first design that has been prototyped. Preece et al. [3] present three types of evaluation methods: *controlled settings involving users, natural settings involving users*, and *any settings not involving users*. The information about the users' interactions and experiences collected by applying any of these methods is used to improve the design of the product or system.

Depending on the type of system, the stage in the product life cycle (PLC) at which the evaluation takes place differs. The goal with the design process may be to develop a completely new system or concept, but it can also concern an upgrade of something that is already existing. The evaluation is distinguished between *formative* evaluations and *summative* evaluations. Formative evaluations are conducted during the design process to confirm that the evolving system meets the users' needs and goals, whereas the summative evaluations assess the product after it has been introduced to the market [3].

## 2.1.3 UX and Software Engineering Processes

It is, as expressed by Preece et al., evident that the UX design process needs to be integrated with the software development process [3]. According to Stephens [13], all development processes within software engineering contain six steps; requirements, design, implementation, verification, deployment, and maintenance.

Traditional software engineering processes were previously often related to the waterfall process, which was first described by Royce [14]. In this process, each step needs to be finished before starting the next. In theory, requirements are stated first in the process and remain unchanged during the following steps. In practice, this has been shown to be difficult to follow, which has resulted in that the waterfall model has evolved into incremental and iterative models. In recent years, the agile development processes have increased in popularity [13]. Agile consists of a set of principles, stated in the "Manifesto for Agile Software Development" in 2001 [15]. From those principles, several techniques have evolved regarding communication, incremental development, and focus on quality in agile development. Such agile techniques are described by Stephens [13]. It is, for instance, to apply continuous contact with customers during the process is emphasised. Additionally, the internal communication is described as often including a large board where the projects status can be followed. Short and frequent meetings with the whole team are also common. In agile processes, incremental development is used, where each iteration is time boxed and relatively short. The goal with every iteration is to achieve a fully tested and high quality application. It is important that the code is well-written from the beginning since the development should be fast.

Even though it is not stated in the agile principles how to integrate UX with the software development processes, some similarities between user centered design and the agile methodologies are identified by Jurca et al. [16]. In user centered design, one key point involves early feedback from the end-users. In comparison, customer satisfaction is the focus in agile development, and in order to achieve that, small working sets of features are frequently delivered to the customers. However, since the customer is not always the same as the end-user, it should be noted that customer satisfaction may not be the same as end-user satisfaction.

Preece et al. highlight another similarity; both the agile processes as well as the UX design process are of an highly iterative nature. The use of relatively short iterative cycles in the agile processes means that the UX activities must be planned so that the results from those activities can be implemented by the software developers at the right time [3]. According to Preece et al., this means that a UX activity may, in practice, stretch over several iterative cycles. In these cycles, it has been decided on beforehand how much of each activity that must be completed at what stage in the cycle. Additionally, implementing one part of the results from the UX activities into the software can also generate new insights concerning the design, which must be taken into consideration when continuing the UX activities. An additional way of addressing the short cycles that is considered by Preece et al., is to conduct as much of the user research before the project begins. This period may also be required from a software point-of-view, since it is often needed to design the technical architecture before any requirements can be implemented in the software. This period is called iteration zero [3].

Preece et al. also provide examples of alternative ways in how to combine UX design and agile processes, with one of which being an approach called *parallel tracks* [3]. As presented by Sy [17], this approach involves performing the UX activities one iteration ahead of the software work, while conducting both processes parallelly. Another agile approach that is described by Jurca et al. is *continuous deployment* [16]. It is considered to aid in improving usability and the integration of UX in the development process . The process allows for frequent deliveries and feedback from users. This is enabled by infrastructure that automatically integrates new code into the live application [16]. Olsson et al. [18] describe a company's evolution towards continuous deployment as "The Stairway to Heaven". The study and the phases in this evolution path are based on interviews with software development companies. The first step involves traditional development, which is followed by agile Research and Development (R&D) organisation, continuous integration, continuous deployment, and lastly, R&D as an experiment system [18].

### 2.1.4 Data-Driven Development and UX

When working with quality requirements within software engineering, there is often an aim to find ways of measuring the quality requirements. As explained by Lausen [6], this is usually conducted by defining a *metric* and setting a numerical target that should be reached, expressed in that particular metric. Data-driven development is a software development principle where metrics related to product quality are continuously collected.

According to Olsson et al., data-driven development is the consecutive step after applying agile processes and continuous deployment. Moreover, a data-driven approach can be applied to the UX design process as well [18].

Olsson and Bosch have outlined the characteristics of data-driven development in [19] and [20]. The collected data is used to estimate the performance of the product, to avoid errors, and to make decisions. *Pre-deployment data collection* is when data is collected before and during the development process. The data typically consists of different kinds of user data, where users are engaged in problem formulation, requirements specification, and validation. Techniques that are commonly used during the development phase are prototyping, A/B testing, observations, and expert reviews [20]. A/B testing is a commonly used technique within web systems, where different groups of customers are presented with different versions of a feature. Data is collected for both versions and a comparison is made in order to evaluate which version that is most appreciated by the users [19]. *Post-deployment data collection* can typically be the time a user spends on using a feature, the frequency of feature selection, and the path a user takes through the system. Post-deployment data can be used to continuously improve the product and serve as a basis for product innovation. Customers can thus be a part of both improving the existing product and developing new products [20].

There are many examples in the literature which describe approaches to how UX can be measured and quantified. Since the term UX incorporates usability, while still extending to a further perspective, the methods that are used to measure the usability are relevant in the context of UX as well. Preece et al. present usability testing as an evaluation method applied in controlled settings, such as usability labs or online, and as being specifically useful to evaluate different kinds of digital applications [3]. Usability tests are emphasised by Sauro and Lewis [21] as the main way of quantifying user research. Tullis and Albert [2] and Lauesen [6] give examples of commonly used usability metrics, such as task time, task success, and problem counts. For instance, a task time metric can be formulated as requiring that eighty percent of the users should be able to perform a certain task within a specified period of time.

With the basis in usability testing, there is an aim of also expressing UX in terms of metrics, as far as it is possible. The aspects of how to decide for, collect, and analyse certain UX metrics are described by Tullis and Albert [2]. The difference between other metrics and UX metrics is pointed out as that the UX metrics reveal aspects of the interaction between the user and the system. These aspects involve effectiveness, efficiency, and satisfaction. Another distinguishing feature of UX metrics is the measurement of the behaviour or attitudes of the people using the system. Tullis and Albert describe eleven different categories of UX metrics. Behavioural and physiological metrics make up one of these categories and involve observing body language and verbalisation during usability tests. Self-reported metrics include surveys and questionnaires. A/B testing is, together with other web analytics and visitor rates, described as a part of live website metrics. Consequently, UX metrics are used both with the aim to elicit software requirements and to evaluate the UX of a system [2].

## 2.2 Internet of Things (IoT)

This section describes the fundamentals of IoT in order to define and provide a general understanding of the concept. In section "2.2.1 Definition", the definition of IoT is discussed, followed by a brief description of some existing and future applications of IoT. Finally, some different models describing the IoT architecture are briefly discussed, followed by a more detailed description of a five layered service oriented architecture.

### 2.2.1 Definition

Internet of Things (IoT) is an emerging technology expected to have a large impact on our everyday lives [22][23]. The term "Internet of Things" was coined by Ashton in 1999 [24], and has in contrast to related terms, such as *Embedded Systems*, *Ubiquitous Computing* and *Wireless Sensor Networks*, increased in popularity in recent years [22]. However, despite the popularity of IoT as a phenomenon, there is no common definition. The International Telecommunication Union (ITU) defines IoT as *"a global infrastructure for the information society, enabling advanced services by interconnecting physical and virtual things based on existing and evolving interoperable information and communication technologies"* [25]. Another definition is given by Cluster of European Research Projects on the Internet of Things (CERP-IoT) as *"a dynamic global network infrastructure with self configuring capabilities based on standard and interoperable communication protocols where physical and virtual "things" have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network"* [26].

To provide an understanding of the wide range of opportunities as well as the complexity of IoT, some example cases listed by Gubbi et al. [22], Atzori et al. [23], and Khan et al. [27] are described briefly. One example of a common IoT application is the *Smart Home*, where typical functions are automated heating, energy consumption management, alarm systems, and light controlling. Moreover, health care applications are also common, which, for instance, involves monitoring of health parameters, activity, and medication. *Smart Cities* and *Smart Environments* include applications such as air quality monitoring, watering, efficient lightning, and exploration of emergency routes. *Smart Grid* is another example that can refer to the monitoring of electricity use, water networks, and agricultural applications. *Smart Transportation* and *Smart Logistics* include functions such as traffic monitoring, emergency reporting, air pollution reduction, and monitoring of transported items.

### 2.2.2 Service-Oriented Architecture for IoT

A key concept within IoT is service-oriented architecture (SOA) [22][23][27][28][29]. SOA means that pre-engineered services, i.e. software units, are provided over a network. The units can be reused and combined, thereby creating applications and infrastructure between services that are enabled through standard communication protocols. Enterprises acquire the services and can thus customise their business solutions with minimal programming effort [29]. Due to the use of standard and platform independent protocols, a SOA approach is suitable to provide interoperability between heterogeneous IoT devices [28]. Several slightly different models are presented in the literature. Gubbi et al. present a three layered SOA, consisting of hardware, middleware, and presentation layer [22]. Another similar SOA is presented by Atzori et al., where the three layers are application, network, and sensing layer [23]. A four-layered model is presented by Xu et al. [28], which includes sensing, network, service, and interface layer. In the SOA described by Khan et al. a fifth layer - the business layer - is also included [27]. This model consists of; perception layer, network layer, middleware layer, application layer, and business layer, and is illustrated in Figure 2.2

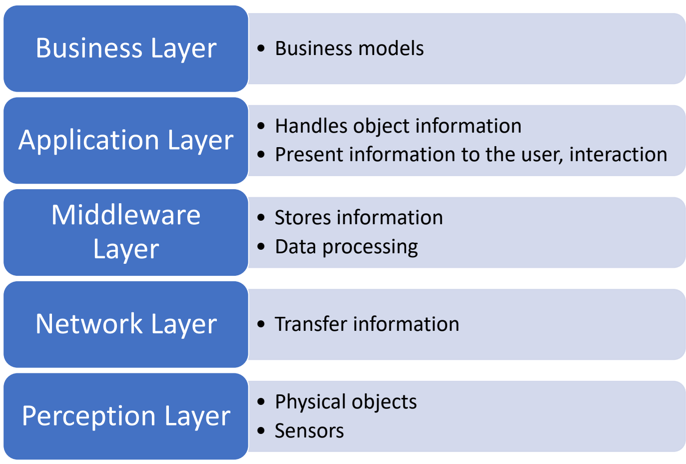


**Figure 2.2:** Example of a five layered SOA model for IoT

The *perception layer*, or device layer, refers to both the physical object itself, the *edge device*, and its sensors. In this layer, identification through the use of, for instance, radio-frequency identification (RFID) and bar codes is handled. Additionally, data collection through various sensors belongs to this layer [27]. Edge devices are divided into four groups by Rowland et al. [30]; multipurpose computers, specialized embedded devices, connected sensors, and passively traceable objects. Embedded devices are typically connected everyday objects or wearables that are able to perform computations and gather data. They can be either directly connected to the Internet or by using a gateway, which, for instance, can be a smartphone. Connected sensors are embedded devices with the only purpose of gathering data from the real world and send it to a network. Passively traceable objects are things that have an identity without being connected to the Internet. Examples of such technologies are RFID, quick response (QR) codes, near field communication (NFC) and beacons [30].

The *network layer* transfers information from the perception layer to the consecutive, middleware layer. Examples of technologies enabling the transmission are 3G, WiFi, ZigBee, Bluetooth, and infrared [27]. Considerations such as energy efficiency, security, and privacy are important for the design of the network layer [28].

The *middleware layer* receives information from the network layer and stores the information in a database [27]. In other words, this layer handles the data processing, information exchange, and data storage [28]. Additionally, automatic decisions based on results from the data processing can be provided by this layer [27], as well as application programming interfaces (APIs) and protocols [28].

The *application layer* handles the object information processed in the middleware layer and presents the information to the user [23] [27]. This can be done through visualisation of both raw data and information drawn from the data [22]. Apart from visualisation, the application layer enables different types of interaction. The objects within IoT typically have no user interface (UI). One way of enabling human-thing interaction with an absent UI is to use agents or gateways, for example a smartphone, tablet, connected TV or computer [30][31].

The *business layer* builds business models from the data acquired in the application layer. This layer will support decision of future actions and strategies [27]. Some frameworks for analysing and designing business models for IoT is presented by Ju et al. [32] and Leminen et al. [33]. Two key factors of creating business models and creating value for the customers consist of data analytics and open ecosystems [32].

# Chapter 3

# Literature Review

This chapter is assigned to a literature review, where the two main topics of this thesis are connected by placing UX in the context of IoT. The aim with the literature review is to cover relevant literature addressing UX for IoT and specifically, the research questions in Table 1.1. There is, to our knowledge, no previously published literature review on UX for IoT. However, Rowland et al. have written a comprehensive book on the subject, *Designing Connected Products* [30]. We will refer to Rowland et al. through this section to place the different subareas in the larger context.

In section "3.1 Method", the method used for conducting the literature review is outlined. In section "3.2 Results", the topics that were found in the literature, related to the research questions stated in Table 1.1, are described.

## 3.1 Method

In this section, we describe the method that was followed in order to conduct the literature review. Firstly, a brief summary of the process is given including the search strings. This is followed by a description of the search strategies that were applied; Systematic Literature Review (SLR) and Snowballing. Thereafter, search results are provided.

The literature review is based on an extensive literature search following the guidelines by Kitchenham and Charters [34] and Wohlin [35]. These guidelines describe how a Systematic literature review (SLR) and Snowballing can be conducted, respectively. Snowballing is an iterative process where references and citations of selected articles are reviewed in a structured way to find additional papers to include in the literature review [35]. However, it should be noted that this literature review is not a complete SLR. While a SLR is beyond the scope of this thesis, we followed the search guidelines by Kitchenham and Charters to ensure that as much of the existing literature as possible is studied. The guidelines also include instructions on how to perform the data extraction from the literature [34]. In our literature review, we mainly applied the SLR and Snowballing search strategies. The data extraction in our study was performed by first sorting the articles by theme, then outlining the main findings from each article, and finally, placing it in context of the others.

The literature review process, which is summarised in Figure 3.1, was initiated by applying a search method of a more random character, both on Google Scholar and in databases (ACM, IEEE, Scopus, and ScienceDirect). Our objective with the initial search was to find relevant synonyms, identify related areas, and provide a general picture of the research area. Subsequently, we selected four data bases for the systematic part of the literature search; ACM, Scopus, IEEE and ScienceDirect.

During the initial search, we concluded that most relevant literature on the subject had been published during the last five years. Therefore, the systematic search was limited to literature published from 2010 and onwards. We made the assumption that relevant literature published before 2010 is cited in later publications and would thus be found during the snowballing procedure.

Kitchenham and Charters emphasise the need for complementary search methods is [34]. Therefore, we applied snowballing after completing the search part of the literature review. Literature found during initial and systematic searches was used as a start set for the snowballing. Through two iterations, the snowballing added four articles to the final collection of articles that are included in this literature review. Due to the emerging interest in the topic of IoT, several articles have been published during the course of the work with this thesis. In order to include even the most recently published articles that are relevant for this literature review, we complemented the systematic literature search with a finishing search on Google Scholar. At this time, we had acquired a more extensive understanding of the subject area and a clearer picture of the existing research. For instance, articles only focusing on interaction were excluded during the systematic literature search. However, as the work proceeded, interaction was seen as more relevant to include.

The search strings that were defined prior to performing the literature search are presented in Table 3.1. The number of articles found in each database and selected for the literature review can be found in Table 3.2.

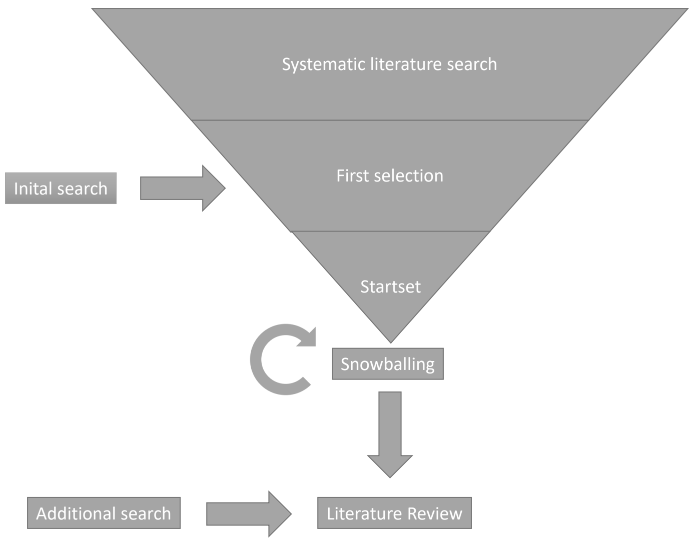


**Figure 3.1:** Overview of the method for the literature review

**Table 3.1:** In order to find literature addressing the research questions, three different search strings were defined prior to the literature search

| | |
|---|---|
| ST1 | *("internet of things" OR "IoT") AND ("usability" OR "user centered" OR "user study" OR "user experience" OR "UX")* |
| ST2 | *("usability" OR "user experience" OR "UX") AND ("analytics" OR "data-driven")* |
| ST3 | *("internet of things" OR "IoT" ) AND ("analytics" OR "data driven") AND ("metrics" OR "non functional requirements" OR "quality requirements")* |

**Table 3.2:** Number of selected articles from the different databases during the SLR, initial search, snowballing and additional search.

| **Database** | **Number of search results** | **Number of articles after title and abstract selection** | **Number of articles included in the review** |
|---|---|---|---|
| ACM Digital Library | 327 | 23 | 0 |
| IEEE | 395 | 20 | 3 ([36], [31], [37] ) |
| ScienceDirect | 87 | 13 | 2 ([38],[39] ) |
| Scopus | 894 | 40 | 4 ([40], [41], [42], [43]) |
| Various (initial search) | - | - | 2 ([44], [23], ) |
| Various (snowballing) | - | 6 | 4 ([45], [46], [47],[48] |
| Various (additional search) | - | - | 6 ([49],[50], [51] [52], [53],[54]) |
| *Total* | | | 21 |

# 3.2 Results

The results from the literature review are presented in five sections. In section "3.2.1 Design Processes", design methodologies proposed for IoT are presented. In section "3.2.2 Evaluation and Data-Driven Development", common evaluation methods, data-driven UX design and data-driven industrial design are discussed. In, in section "3.2.3 Distinguishing Properties of IoT", identified IoT properties that are related to UX are listed. Furthermore, in section "3.2.4 Interaction", the perspective of interaction and the human role within IoT is discussed. Finally in section "3.3 Reasearch Gap" reasearch gaps related to the findings are outlined.

## 3.2.1 Design Processes

The general UX design process was outlined in section "2.1.2 UX Design". Moreover, it was also mentioned that most design processes include similar phases and activities.

Therefore, this section covers the literature which describes design methodologies that have been applied when developing IoT and the identified differences to these methodologies when comparing with the UX design process. The section is concluded with presenting the challenge of how IoT requires a close collaboration between UX designers and industrial designers.

## Design Methodology

Both Fauquex et al. [36] and de Haan [41] regard some characteristics related to IoT as a reason for changes in the design methodology. The key drivers of this change are considered by de Haan as the extended interaction possibilities, mobile and wireless networks, social and collaborative applications, connected data, and the use of intelligent and sensitive agents. The differences in interaction with IoT also form the basis for the refinement of the UX design process that is made by Fauquex et al [36]. The diverse nature of interaction possibilities with IoT, results in that the product being developed will be part of a whole ecosystem of devices. This is taken into account in the design methodology presented in [36] by adding two introducing steps to the UX design process: "discovery" and "capturing". The purpose with these steps are presented as involving research and identification of the users and the context, where the research is performed from an even more holistic perspective than in the *analyse* phase of the traditional UX design process.

The design methodologies are, according to de Haan, shifting towards being more iterative, incremental, and prototyping-based with less focus on process requirements to give way for what is relevant to the end-product [41]. The ways in which IoT affects the design methodology and processes are described as increasing the importance of the user-centeredness of design, increasing the use of higher level tools, and applying new, agile, and exploratory design methods. In accordance with these factors, the two introductory steps in the methodology in [36] involve additional emphasis of the user-centered and exploratory character of the UX design process. Moreover, the prototyping as an increasingly essential part of the process coincides with one of the guidelines in [45], where it is recommended by Kranz et al. to apply rapid prototyping by using different prototyping tools in order to create early prototypes.

The factor of an increased use of higher level tools, is elaborated by de Haan as that the availability of programming tools at higher levels of abstraction facilitates the translation of user issues into software [41]. Thus, the designers become less dependent of adopting to the software development process and more focused on the development of concepts and ideas. These higher level tools also enable applying the concept of end-user development (EUD) within IoT, which is covered by Barricelli and Valtolina [38] and Carlson et al. [46]. EUD extends the notion of user-centered design into also enabling the users to actively participate in designing for UX. In comparison, de Haan explains that the user-centered approach extends with the evolvement of the design processes into a further involvement of the users in the design process, in terms of co-creation and co-design [41]. While EUD is not specific for IoT, Barricelli and Valtolina mention that the increasing use of wearables both enables and requires that the different sensors and their collected data can be managed and adjusted according to the desires of the user [38]. However, they describe that many of the currently available EUD tools still use programming as the central metaphor. To address this, they present a graphical model for defining event-based rules in a mobile application. Similarly, Carlson et al. adopted a graphical approach to enable users to discover, connect, and share their smart space configurations [46]. They agree with de Haan by envisaging that these type of tools will be useful for designers as IoT becomes an increasingly natural part of everyday environments. The tools enable the designers to focus on creating innovative user experiences instead of IoT interoperability issues [46].

### Industrial Design

Rowland et al. consider the combination of hardware and software design as the distinguishing part of the design methodology for IoT [30]. They regard it as a new design discipline, in which it is required by digital UX designers and industrial designers to collaborate deeply. Consequently, they emphasise some characteristics of industrial design that digital UX designers should give special consideration to. As one of those characteristics, they consider the less iterative nature of the industrial design process when comparing with the UX design and software development process. Accordingly, de Haan describes an increased ability to resolve design issues by exploration and experimentation mainly from a software development point of view [41]. Specifically, de Haan explains that the more agile and exploratory character of the design processes results from that the designers become less concerned with deadlines for deliverables.

Moreover, the frequency of interaction with the device, the visibility of the device, and the number of devices that each user will own are also mentioned by Rowland et al. as factors that affect the physical design differently when comparing with the digital part [30]. In the context of visibility, Kranz et al. [45] discuss how to add user value with focus on connecting products that is not traditionally connected. They base the discussion on the *invisibility dilemma* that occurs when making everyday objects smart. Kranz et al. consider it a key design element to hide the augmentation so that the object appears to be the same as when not connected. However, even if the sensing, actuation, and interaction is hidden to the eye, users must still experience an added value to appreciate that the object is connected. To maintain interest over time, Kranz et al. emphasise the importance of being careful when designing products to avoid accidental use. If the user is afraid of involuntary using the system, it is likely that the user stops using the device.

## 3.2.2 Evaluation and Data-Driven Development

*Evaluation* is in section "2.1.2 UX Design" presented as the last phase of the UX design process. In section "2.1.4 Data-driven Development", the use of UX metrics are brought up as an evaluation method that is gaining increasing interest. This section outlines which evaluation methods that have been found in the literature to be applied when developing IoT. Since industrial design was described in section "3.2.1 Design Processes" as an important part of IoT development, the data-driven approach is considered from the perspective of both UX design as well as industrial design.

### Common Evaluation Methods

As previously mentioned, there are several ways of conducting the evaluation in the general UX design process. Within the development of IoT systems, user tests are common to find in the literature [36] [38] [40] [46], and there are examples of different types of standardised user measurement protocols that the users fill in after the test. System Usability Scale (SUS), Computer Usability Satisfaction Questionnaire (CUSQ), and User Experience Questionnaire (UEQ) are examples of such protocols that are used in [38]. SUS is also used by Carlson et al. in [46]. Nazari Shirehjini and Semsar use the ISO-Norm 9241/110 [5] questionnaire to evaluate the usability in [40]. The formulation of a test protocol is mentioned by Fauquex et al. as part of the future work and the aim is to base it on heuristic evaluation and usability testing [36]. Heuristic evaluation is often applied when users are not easily accessible or as a complementary usability inspection method and involves feedback provided by experts [3]. Moreover, the user tests can also be complemented with interviews with the participants or by conducting observations [36] [38]. Other UX evaluation methods that are mentioned, both quantitative and qualitative, are bipolar surveys, log-data analysis, data mining for identifying behaviour and usage patterns, and ethnographic studies [37]. There are also examples of emerging development and evaluation methods which apply virtual reality (VR) and augmented reality (AR). For instance, this is covered by Seo et al., where interactive visualisation provides a way of understanding and experiencing a smart home environment before it is implemented in reality [39].

An issue with applying usability testing within IoT is raised by Thomas et al [55]. They consider the lack in usability dimensions and guidelines for IoT. They highlight that the available guidelines are intended for desktop and web based applications and systems. This limitation is also identified by Nazari Shirehjini and Semsar, who mention that two of the questions from the ISO standard were removed since these were only applicable in the context of desktop applications [40]. By presenting a number of usability evaluation criteria for IoT, Thomas et al. attempt to address this problem. The evaluation criteria originate from the fundamental usability criteria; flexibility, operability, learnability, and understandability [55]. These were adjusted according to the properties of IoT, where some of which were outlined in section "3.2.3 Distinguishing Properties of IoT".

### Data-Driven UX Design

Apart from the usability testing and other quantitative and qualitative evaluation methods, the quantification of UX that was discussed in section "2.1.4 Data-driven development" is also applied within IoT. For instance, Fauquex et al. mention that a way of measuring the users' satisfaction with the developed product is a future focus in their study [36]. As covered in section "3.2.1 Design Processes", it was concluded by de Haan that the characteristics of IoT enable a more data-driven approach to the design process [41]. This is also supported by Olsson et al., who argue that the increasing connection to the Internet among embedded systems provides the potential of continuously performing different user experiments, such as A/B testing [19]. Moreover, the use of metrics as usage estimates is also emphasised in the design guidelines in [45] as a way of supporting the development and evaluation.

Pallot et al. have identified IoT-specific UX metrics [37]. According to them, there is in general more research conducted that considers UX evaluation rather than UX measurement, which they explain as being due to the subjective nature of UX. This motivates their study, in which they present a UX framework and model within the Experiential Living Labs for IoT applications. A *Living Lab* is described in [37] and [41] as a user-centered research methodology which exploits the real life environment for the development and evaluation of complex solutions. By providing a certain part of reality with facilities to observe and register the behaviour of different stakeholders, and particularly the users, the Living Lab is considered by Pallot et al. to be an iterative, experiential design process situated in an open innovation ecosystem [37]. Their UX model constitutes three identified categories: knowledge, social, and business. This refined holistic view of the concept of UX resulted in an identification of approximately 40 different metrics, distributed among the three UX categories. Pallot et al. extract three of those as being some of the most common UX elements specifically concerning IoT; automation level, connectivity, and reliability.

### Data-Driven Industrial Design

The perspective of how the data-driven design approach is addressed when the physical product form is taken into consideration is covered both by Rowland et al. and Lin et al. [30] [42]. Rowland et al. emphasise that the use of measurements and analytics to make decisions and improve the system continuously after it has been released to the market is not applicable in industrial design. This is due to the fact that changes to a physical product can rarely be made after it is manufactured. They declare that there is therefore a *design freeze point* in physical design projects. At this point, the design is handed over to the manufacturers. Consequently, Rowland et al. describe that industrial design is more dependent on upfront research, prototyping parallel design alternatives, and conceptualising the product [30].

Despite these challenges, Lin et al. present a framework for how to combine the data-driven approach with product form design [42]. The main part of the framework consists of conducting a UX scenario experiment with the wearable in question. During the experiment, user information data, perception data, UX decision data, and data from the wearable itself, are collected. According to Lin et al., the aim is to use this data in order to derive key product form factors and a suggestion for choosing the direction of the research and development (R&D) work, specifically related to the product form. However, they conclude that the limitation of working iteratively with the physical object results in that the presented framework can mainly be used by newly launched products with short life cycles, thereby making it mainly adapted to wearables.

## 3.2.3 Distinguishing Properties of IoT

From the literature, we identified some properties that, in several articles, were considered to be important or challenging when it comes to UX for IoT. In this section, we present these properties under four major themes: privacy and security, context, hedonistic properties, and interoperability.

### Privacy and Security

The most extensive research direction within IoT is the challenge of how to create secure systems that do not violate the user's privacy [23] [51]. However, the connection between UX and security is hardly discussed. According to Rowland et al., there is often a conflict between security and usabiltiy. A common UX trade-off concerns the conflict between rigorous authentication and ease of interaction. One key UX challenge is to make the users use the security measures correctly [30]. Rowland et al. describe security as a network issue whereas privacy is described as a network data issue. Privacy is both about collecting, storing, and sharing personal data [30]. Oh and Lee are discussing UX issues related to wearables [43]. Most UX issues were found to be related to data; data controllability, data integration, data visualization, and data accuracy. Moreover, sharing and privacy were also identified as issues [43]. Similarly, Thomas et al. declare that it is, in the context of usability for IoT, necessary to be aware of data storage procedures and to format the information advisedly [55]. In contrast, Hsu and Lin have shown that concerns regarding information privacy had no influence on user attitude towards IoT [48]. However, when the aspect of the intention of continued use of the device is taken into consideration, a significant effect of concerning for information privacy could be seen [48].

## Context

According to Thomas et al., both the users and the environment in which the IoT system will be used must be defined in order to be able to specify user requirements [55]. Also Rowland et al. emphasise the comprehension of the *context of use* in order to understand user needs. Rowland et al. introduce four ways of defining context that affect UX for IoT; socio-cultural, ecological, behavioral, and operational. According to Rowland et al., UX designers must be careful when correlating context information to user intentions. If the assumptions are wrong, the UX may suffer [30].

## Hedonic Perspective

The increasing use of wearables is referred to in [38] as the *quantified-self* movement, which incorporates the tracking of various parameters such as habits, behaviour, and health conditions. In [43], Oh and Lee discuss UX issues for quantified-self. It is stated that the wearables are often regarded as fashion items and therefore, favorable aesthetics is emphasised. Additionally, the size and shape are said to play an important role in order not to disturb the user. Engagement is another UX issue that is identified in the way that the importance of fun is emphasised when choosing what IoT tools to use. On the other hand, there is a risk with quantified self technologies to create over-engagement. In order to avoid this, the users need detailed guidelines on how to make sense of the data [43]. Also Shin stresses the use of a hedonic perspective on IoT by discussing affordance and coolness as contributing factors [50]. Shin propose quality of experience (QoE) as an evaluation method for IoT. The need for balancing the quality of service (QoS) and QoE to make a user-centric evaluation is argued. Since IoT is enabled by technology, QoS is considered to be applicable to evaluate the technical aspects. However, there is also a need to evaluate the user perspective which can be done by applying QoE evaluation. Furthermore, it is highlighted that UX and QoE are considered to be different concepts. Shin describe QoE as being related to content, service, and system, whereas UX is related to usefulness and enjoyment. Affordance and coolness are placed in-between UX and QoE. However, it was shown to be closer related to QoE [50].

### Interoperability

One conclusion that Kranz et al. make in [45] is that the use of devices or interaction techniques that are specialised for a specific task or target users, should be preferred over generic devices. The subject of generic versus specific applications is discussed by Rowland et al. in the context of UI. Using generic apps that can handle different devices from different manufacturers may compromise the function of the device compared to a specific app. Furthermore, they mean that this can result in difficulty in organising a number of different apps and in finding the right app [30]. In that way, this can be viewed as creating interoperability issues that are originating from the difficulty in building an ecosystem of smart products that work together, independent of manufacturer.

The participating companies in the study by Olsson et al. see the transition towards heterogeneous ecosystems as critical in adding user value and maintaining interest over time [44]. In this case, the ecosystem dimension refers to the interconnection other external systems. Rowland et al. list some additional interoperability issues that are assumed to affect UX: lack of standardisation, difficulty of knowing which devices that can work together, coordinating devices, organizing devices, and accessing controls. In accordance with Olsson et al., Rowland et al. refer to that closed ecosystems limit the users and hold them out of control from their own data and devices, which may limit the UX quality. In [55], where Thomas et al. discuss usability criteria for IoT, one of the main criteria involves ensuring that various IoT systems can interoperate with each other as well as be integrated in a new environment without affecting the service to the user.

Factors for continued use of IoT devices are discussed by Hsu and Lin [48]. It is indicated that network externalities have significant impact on the user's perceived benefit and adoption of the IoT system. Network externalities is defined as "the value or effect that users obtain from a product or service will bring about more value to consumers with the increase of users, complementary products, or services" [56]. However, no significant effect of the number of IoT devices on the continued use could be shown [48].

## 3.2.4 Interaction

As described in section "2.1.1 Related Concepts", UX and interaction are closely related subjects. Since IoT enables new ways of interacting, this also results in new challenges for UX designers.

### Human in the Loop

One research direction within IoT interaction is *human in the loop*. This concerns where human behavior becomes a part of the system instead of being an external and unknown factor [51] [52]. In [51], four categories of human in the loop applications are listed; "applications where humans directly control the system", "applications where the system passively monitor humans and take actions", "applications where psychological behaviour of humans are modeled", and hybrids of the previous three categories. As the communication between objects increases, the human role possibly becomes more complicated, according to Cervantes-Solis et al. [47]. They mean that when objects exchange information, the user can either eavesdrop on the messages being sent and thereby determine the system's goals, or be a part of the exchange [47]. Fauquex et al. argue that there are additional differences when interacting with IoT compared to traditional interaction; firstly, that many users can interact with many devices integrated in the environment, and secondly, that devices can interact with each other [36].

According to Nunes et al., there are three different human roles in an IoT system; humans can either carry devices that collect data, make decisions based on what they observe in the environment, or interact physically with the environment as an actuator [52]. To investigate the role of the user within IoT, it is important to explore how people make sense of smart objects. For instance, this is done by Cervantes-Solis et al [47]. They stress the dilemma of both making sense of the function of each individual object and the discovery of the overall pattern. They also highlight that it is more important to focus on the higher level outcome of the activity than the functions of each object [47].

## Interaction Models

A common way of enabling interaction within IoT is to use mobile agents. A model for such interaction is presented by Leppänen et al. in [31]. Nazari Shirehjini and Semsar propose another approach for interacting with seamlessly integrated devices is to use a 3D UI for a mobile agent [40]. Moreover, interaction models such as gestures, speech, and tangible interfaces as well as context aware interaction are proposed by, among others, Hossain et al. [53]. However, interacting with a device that is integrated in the environment by, for example, gestures is difficult, especially if the environment is unknown to the user [40]. As mentioned by Rowland et al., gestures are also considered a less appropriate input when there is no time to learn, when precision is needed, and false positive recognition can have serious consequences. Voice and audio are also suggested as interaction models for both input and output. Rowland et al. mean that these types are convenient for urgent alerts, to give products emotional qualities, and for contexts where hands free interaction is beneficial, but they can be annoying in some contexts and hard in noisy environments [30]. Tangible interfaces are described as interfaces where manipulating tokens or the placement of the device provides input [30].

Depending on both user and context, different interaction types are more or less appropriate. One way of taking this into account is context-aware interaction, where the user receives automated support based on context or situation [53]. According to Gilman et al., interaction with smart spaces is generally context-aware and can be divided into four categories; user-to-recourse, recourse-recourse, user-to-user, and facilitated interaction [54]. Facilitated interaction is referred to as interaction with smart spaces in order to achieve some social benefit. Rowland et al. also discuss context-sensitive interaction. The interaction is then described as dependent on context, such as user identity, weather, or time of the day. Context-sensitive interaction demands less user attention and reduces the requirement for interaction. The device should ideally understand the user's desire depending on the context. It should take action while still leaving the user in control, which is a critical design challenge. In [53], Hossain et al. argue that users feel less trust in fully automated systems. Therefore, a dynamic interaction mechanism is proposed, which adjusts the level of implicit interaction based on the quality of context information. Companies participating in the study by Olsson et al. expect that successful IoT systems will require less human intervention over time and thus, dynamic interfaces should be preferred over exploratory

[44].

## 3.3 Research Gap

As can be seen in section "3.2.4 Interaction", there is relatively extensive research done on interaction for IoT. Also design methodologies (section "3.2.1 Design Processes") and evaluation methods (section "3.2.2 Evaluation and Data-Driven Development") for IoT are investigated to some extent. However, most literature considers the topic from an academic perspective. Ovad and Larsen have conducted a study on UX and usability in eight different Danish companies, among which three were software companies and five were companies working with embedded software in physical products [49]. They argue that there is a gap between industry and academy when it comes to UX and usability methods.

We have noted that previous research rather focus on specific methods or solutions than on the broader picture of UX. Moreover, the results are rarely generalisable. However, Shin attempts to provide a broader picture by considering QoE as an evaluation method for IoT and has identified a gap in research of UX and costumer satisfaction when it comes to IoT [50].

There is, to our knowledge, no research on how IoT companies in specific view UX, include UX in their development processes, or evaluate UX of their products. Even though companies that work with embedded software are included in the study by Ovad and Larsen, the main focus is on how to combine agile development methods with UX [49]. Olsson et al. conducted a study on five different Swedish companies view on interaction and ecosystems for IoT. However, this study do not cover the broader picture of UX [44].

To conclude, we have identified two major research gaps within IoT. Firstly, there is a lack of research of UX from a broader perspective with focus on main challenges rather on specific methods and case studies. And secondly, there is limited research performed on the view of UX for IoT from an industry perspective.

# Chapter 4
# Empirical Study

In this chapter, we describe how the empirical study was conducted as well as the findings from the study. In section "4.1 Method", the execution of the empirical study is described. In "4.2 Participating Companies", all participating companies and interviewees are introduced. In section "4.3 Results" the findings from the empirical study are presented.

## 4.1 Method

This section consists of an outline of the formulation and the execution of the empirical study. How the analysis of the qualitative results was performed is also described. The empirical study was formulated as an exploratory case study, which included a number of 13 interviews. An overview of the method for the exploratory case study can be seen in figure 4.1. In section "4.1.1 Formulating the Exploratory Case Study" the choice of a qualitative research method is discussed. In section "4.1.2 Conducting the Interviews" selection of participants, formulation of interview questions, and a description of how the interviews were performed. Finally, in section "4.1.3 Analysing the Interviews", the data extraction and analysis of the interviews are described.

### 4.1.1 Formulating the Exploratory Case Study

In software engineering, there are mainly five different types of empirical research methods that are used: case studies, controlled experiments, surveys, action research, and ethnographies [57]. These are in turn categorised as being either of a quantitative or qualitative character [58]. Considering the exploratory nature of this study and the aim to describe the diversities among companies within the defined area, the qualitative approach was found to be the most suitable [59]. Quantitative methods are more appropriate when it is important to ensure a higher degree of objectivity and repeatability than qualitative methods can do. Moreover, quantitative methods provide results that are analysed using statistics, and are therefore, in some perspectives, more straightforward to analyse [57].

The study was formulated as an *exploratory case study*. This empirical research method is preferred when a certain, contemporary phenomenon is to be studied in its natural context. It offers a way of gaining insights on how and why the phenomenon occurs and, based on these insights, new hypotheses, ideas, and theories can be derived [57]. By conducting the exploratory case study, the objectives were to obtain a clear overview of how different companies take UX into account in the development process for IoT; if and how a data-driven approach is used; and to explore the challenges of considering UX within the context of IoT.

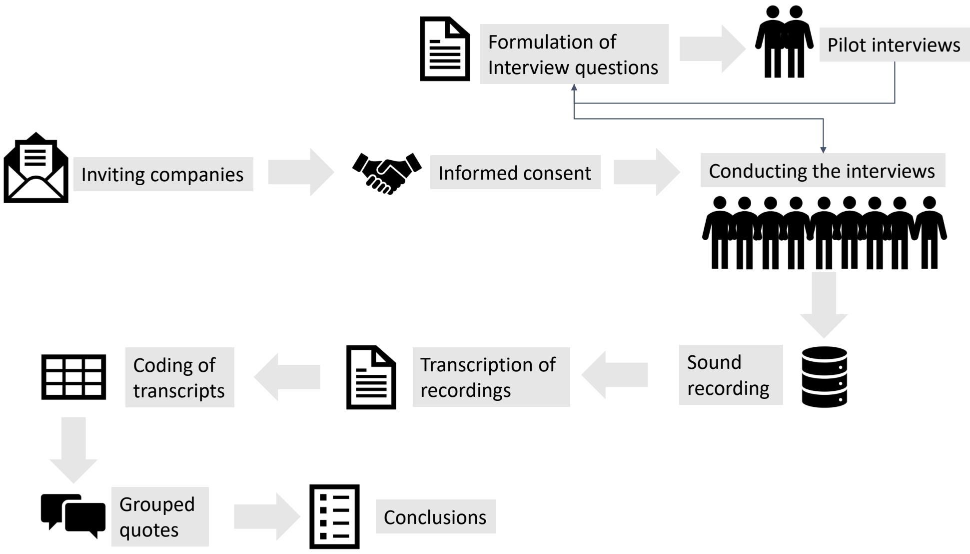


**Figure 4.1:** Overview of the method for the exploratory case study.

## 4.1.2 Conducting the Interviews

With the objectives of the case study in mind, we contacted several companies in the surrounding area of Lund and Malmö, Sweden. The precondition for contacting a company was that it somehow operated within the field of IoT. Companies that only develop platforms for enabling other companies to develop IoT were excluded, since the end-users of such platforms do not correspond to those of the resulting IoT services. It was of high value that the interviewee was well informed about the development process of their products. Initially, the participating companies were included by applying convenience sampling [59][60], which meant that all companies that accepted the offer were also scheduled for interviews. When interviews with seven companies had been planned, we made a mapping of these companies according to their size and whether they were product companies or consulting companies. It was found that both small and large consulting companies had been included. Since there was only one small product company on the list by the time, additional product companies of various sizes were contacted and, fortunately, four of these took an interest in participating. Thus, the selection of companies had been made by using a combination of convenience sampling and maximum variation sampling [59][60], with the result that the empirical study eventually consisted of interviews of both consulting companies and product companies of different sizes. Combining this sampling method with the involvement of interviewees in different roles at the companies, contributed to the diversity of the perspectives on the subject [58].

To collect the data, *semi-structured interviews* were performed. This is a common data collection technique in case studies. It involves questions that are planned on beforehand but, in contrast to *fully structured interviews*, the interviewer is free to choose the order in which the questions are asked. Consequently, this allows for follow-up questions and a mutual exploration of the subject [58]. Thus, this structure of the interview suited the exploring character of our study well.

The interview instrument that we constructed can be found in Appendix A. The semi-structure of the interview involves a mixture of open and closed questions. The interview instrument was structured according to the *funnel model*. In that way, the character of the questions moved from general to specific [58]. By making use of the similarities between the structure of this study and the one presented by Karlsson et al. [59], several of the questions were defined similarly, with some adjustments to address the objectives of this particular study. The instrument was tested by conducting two pilot interviews and some questions were adjusted according to the feedback provided. The structure of the instrument was also altered by ensuring that the order of the questions followed the time line of a product life cycle (PLC). Each interview was initiated with an introduction of the objectives of the study, followed by introductory questions where the interviewee was asked to describe the company, their products, and the responsibilities and work tasks that the interviewee's role involved. Subsequently, the main part of the interview was initiated. This part was divided into three subparts. The first one consisted of questions regarding UX and the development process, the consequent part involved data driven development, and the finishing part involved questions aiming to combine these two subjects. All interviewees were provided with a consent agreement on beforehand to be ensured of confidentiality and anonymity, and to be able to give informed consent [58]. The informed consent is provided in Appendix B.

All interview sessions were recorded using a dictaphone. During the first interviews, one of the authors was responsible of being the main interviewer while the other took notes, ensured that all prepared questions were asked, and asked follow-up questions. However, it was soon discovered that both the dynamic of the interviews as well as the tendency to ask follow-up questions were improved when we asked the questions alternately. Thus, we conducted the rest of the interviews with less strict roles.

### 4.1.3 Analysing the Interviews

To be able to analyse the interviews, the recorded sessions were transcribed using the tool oTranscribe [61]. The analysis consisted of coding the transcripts. This involves dividing the qualitative data into parts with coherent content and assigning codes to these different parts [58]. In qualitative research, the coding is usually conducted by applying the two main types of data analysis methods: *generation of theory* and *confirmation of theory*. The aim of theory generation methods is to find hypotheses from the data, whereas theory confirmation methods are used to find support for previously generated hypotheses.

A combination of methods from both groups is often applied in order to generate both grounded results as well as evidence that support those results. Such a combination of methods was applied in this particular study as well.

The formulation of the codes can be made either before or after the collection of the data. In our case, the objectives of the study were clearly stated on beforehand, which motivates the use of an initial set of *preformed codes*. These codes originated from the goals of the study, the research questions, and other related variables of interest. As the analysis progressed, a number of codes were added. These *postformed codes* were found iteratively by identifying recurring themes in the data and finding text parts which could not be coded with any of the preformed codes [62]. The majority of the codes consisted of preformed codes.

We followed the suggestion provided by Runesson and Höst [58], and used tabulation as technique for the coding. The data and the codes were organised in a table where the passages of text were placed in the first column and the remaining columns represented the codes. The first interview was coded separately by both authors and combined into a resulting coded transcript. Because of the similarities between the selected codes of each author, the consequent interviews were equally divided between the authors instead. After a transcript had been coded by one author, it was validated by the other. If there were any disagreements regarding the assignment of codes, the particular text part was immediately discussed in order to agree on a final selection of codes.

After assigning codes to the different passages of text, we used a theory generation method referred to as the *constant comparison method*. This meant that we grouped the passages into patterns according to the codes. From the groupings, underlying themes and explanations of phenomena were identified, and these formed the basis for the conclusions that could be drawn from the study [62]. In specific, we compiled the results by identifying which of the three research question that the topic of each code was most closely related to. For example, we studied passages in each transcript that had been assigned codes related to the development process, such as "UX activities" and "Organisation", and summarised those passages into an answer to RQ1 in Table 1.1. The summaries were written with the aim of representing all different aspects, similarities, and varieties that could be found in the data. Since a clear distinction between two groups often could be found, where a grouping according to "consulting companies" and "product companies" was the most common one, we mainly conducted *cross-case analysis* [62]. This meant that we identified similarities within each group as well as differences between the groups.

## 4.2 Participating companies

Out of the 33 invited companies, 11 companies represented by 13 interviewees participated in the study. In this section, the participating companies are presented as well as the interviewees and their role at the company. A summary of the characteristics of the participating companies is presented in Table 4.1.

## Company A

Company A is a consulting company operating in industrial automation and product development. The company was founded in 1985 and has about 600 employees. The consultants can work either in-house or as a part of the customer's organisation. The customers vary from large, global software companies to small companies. Company A is specialised in embedded systems and has been working with IoT for one year.

The interviewee is a senior software developer specialised in embedded systems who has recently worked with the long term strategy for IoT and mobile applications within the company. The interviewee has worked for Company A for eleven years, and was before that employed by a large product company.

## Company B

Company B is a consulting firm that designs and develops solutions within IoT. It was founded in 2013 and collaborates with other companies within different industries, such as the interior, automotive, and health care industries. They also apply some in-house development. There are approximately 270 employees working at the company. Their expertise ranges from engineering to design and involves all parts that are required when developing for IoT.

The interviewee is the head of the design team, which involves having the responsibility for building and maintaining customer relationships, leading and engaging in projects, and participating in the development of the company. The interviewee is an experienced industrial designer and has previously worked at different large mobile- and telecommunication companies for over 15 years.

## Company C

Company C is a consulting company specialised in IoT and has three business focus areas; industrial IoT, e-health, and energy. The company was founded in 2015 and has around 10 employees. Company C works mostly with business customers but they also conduct in-house projects where they work with their own ideas.

At Company C, two persons were interviewed together; the CEO and an industrial designer. The CEO has over ten years of experience from a large telecommunication company. The industrial designer has been employed as a consultant at Company C for a couple of months and has previous experience from interior and product development. The CEO will be referred to as Interviewee C1 and the industrial design ass Interviewee C2.

## Company D

Company D is a start-up company, whose product is an edge-processing sensor that is used within retail and facility management. The company was founded in 2013 and about 10 employees works at the company.

The interviewee is the company's sales director and describes the role as being *"between the developers and the CEO"*. The interviewee is responsible for everything that is related to the product market, which includes both looking at new features and usage data, but also marketing and sales. The interviewee has a background as sales manager at a large telecommunication company.

## Company E

Company E is a product development consulting company developing both software and hardware. The company supplies customers with additional resources on occasion, but their main business concerns product development. Their customers range from very small to large. The company is 30 years old. Initially, the development mainly revolved around electronics. Today, they are 45 employees, of which one third is hardware engineers and two thirds are software engineers.

Two separate interviews were held at the company; one with a software developer and UI/UX designer and one interview with one of the R&D managers. The software developer has worked at the company for ten years and has a multifaceted role as technical lead and developer as well as working with UX and UI when needed. The R&D Manager has a background as electrical engineer and has previously been working with software development. Now, the interviewee is primarily working administratively and is responsible for the company's quality and environmental work as well as being the head of the project management team.

The software developer will be referred to as Interviewee E1 and the R&D manager as Interviewee E2.

## Company F

Company F is a global IT management company with 68 000 employees worldwide. The company has been operating for 40 years and has about 4000 employees in Sweden. They provide various industries with IT solutions and services, and the interviewee describe that they have more than ten years of experience withing M2M and IoT solutions. The interviewee is Lead of IoT in Sweden and was previously responsible for their own global IoT/M2M platform.

## Company G

Company G is a design studio that participates in different parts of their customers' processes. They deliver project based consulting and develop concepts, pitches, stories, and visions. Depending on the customer and the project, they can either work in teams together with the customer or separately. Moreover, they also work on their own product that is to be released.

The interviewee is an interaction designer and has the role as head designer at the company.

## Company H

Company H is a large mobile communication company. The interviewee works at an innovation department which has its own development process and is relatively independent from the rest of the company. The ideas that are incubated at the department come from employees at Company H who can post ideas into a forum. The department has 100 employees and was started in 2015. At the time of the interview, no product developed at the department had been released to the market. When a product is to be released, there are different set-ups in how this can be done; it can either involve creating a new brand around the product or building a product for a partner company. Interviewee H is *"UX factotum"* at the department and was previously a UI designer at the company. The interviewee has a design and interaction background.

### Company I

Company I is a start-up automotive company that was founded in 2016. There is about 50 people who work at the company, of which 20-30 has an actual employment. There are also master thesis students, internships, and other students working at the company. Interviewee I has worked with the project almost from the beginning, and has engaged in a number of different parts of it. Currently, Interviewee I is mainly involved in electronics and software projects.

### Company J

Company J is a start-up company that develops a wearable. The company was founded in 2015 and there are approximately 70 employees at the company. The employees' background cover all disciplines that the development requires, including industrial design, software development, as well as sales and marketing. Interviewee J is the UX director and is therefore responsible for building and leading the interaction and UX team.

### Company K

Company K is a start-up company that has developed a home security system. The company was founded in 2014 and their product was launched in 2016. They are around ten employees, where most of whom are electrical engineers or software engineers. Interviewee K has a background in product design and is the CEO and one of the founders of the company.

## 4.3 Results

In this section, the findings from the empirical study are presented and the three research questions in Table 1.1 are addressed in four sections. The first two sections addresses RQ1, where in section "4.3.1 Development Process" the development process at each company is described briefly. Followed by section "4.3.2 UX Development" where the companies' development processes from a UX perspective is described by first discussing the UX organisation followed by which UX activities that are performed. The second research question, RQ2, is considered in section "4.3.3 Data-driven Development" In this section we focus on the UX development after the product is released to the market. Finally, in section "4.3.4 IoT UX Challenges" the third research question, RQ3 is addressed by compiling the interviewees' experienced challenges related to UX for IoT.

**Table 4.1:** Participating companies

| Company | Number of employees | Age (years) | Category | Industry | Interviewee(s) |
|---|---|---|---|---|---|
| A | 600 | 30 | Consulting | Industrial automation Embedded systems | Senior software developer |
| B | 270 | 4 | Consulting | IoT | Head of Design |
| C | 8 | 2 | Consulting | IoT | C1: CEO<br>C2: Industrial Designer |
| D | 10 | 4 | Product company | Retail and facility management | Sales Director |
| E | 45 | 30 | Consulting | Various | E1: Software Developer<br>E2: R&D Manager |
| F | 4000 | 40 | Consulting | IT | Lead of IoT |
| G | 10 | 2 | Consulting | Various | Lead Interaction Designer |
| H | 100 | 2 | Product Company | Mobile equipment | Senior UX Designer |
| I | 30 | 2 | Product Company | Automotive | Software Developer |
| J | 70 | 2 | Product Company | Smart consumer products | UX Director |
| K | 9 | 3 | Product Company | Home security | CEO |

### 4.3.1 Development Process

With regard to the description in section "2.1.3 UX and Software Engineering Processes", it can be assumed that the character of each company's development process affects how UX is incorporated in the process. In this part, we thus give an overview of the similarities as well as differences between the companies' development processes. Moreover, as mentioned in section "2.1.1 Related Concepts", there is a relatively close connection between quality requirements and UX. From the UX perspective, it is therefore motivated to study how the companies work with requirements. This description is also provided below. Moreover, the challenge of combining hardware and software development in agile processes is described.

The majority of the interviewees consider that the development process itself or the steps that it involves are not different when developing for IoT comparing with other systems. Instead, several of the interviewees find that IoT mainly introduces a higher level of complexity in the process. Interviewee E2 thinks that IoT development involves larger projects with more parallel tracks, where there are additional things to take into consideration. Interviewee B formulates it as that *"it is a much more complex assignment to remodel [and] design for this time and onwards"*. Additionally, the interviewee stresses that, due to the rise of IoT, different categories of industries meet each other.

However, Interviewee H regards IoT as a contributing factor to the differences in the development process at the innovation department comparing to the one that is applied at Company H at large. Except from that Interviewee H explained that the innovative character of the development demands a more rapid process, the reason for applying a different development model *"is also that it's about Internet of Things. That is to say, it's unknown ground. The values are entirely untried"*.

All interviewees say that they apply an agile and iterative development method at their respective company. In general, all consulting companies have a generic development process which they adjust according to the characterisation of the customer. How much insight the customer receives into the process depends on the customer's demands. One of the main properties that varies among the consulting companies concerns the degree to which their own process is adjusted to and merged with that of the customer. Nevertheless, in the cases where the consulting companies conduct the development in-house, they follow their own development process.

Due to the differences in the character of the product companies, it is difficult to identify general properties of their respective organisations and development processes. However, there are some similarities between them. Company H and J are similar in size and have a similar organisation with teams responsible for their respective expertise areas. Company D and J apply a similar development method with iterative sprints. The interviewees from Company J and K are distinguished by stating that their respective development processes is entirely directed by UX. Both Company I and K have a relatively unstructured way of working. The development process at Company I has, until recently, been of a completely self-organising character. Company H is different from the other product companies in the way that they have developed several products and have formulated a generic development process that they, similarly to the consulting companies, apply in their different projects.

The degree to which the companies work with requirements in their development processes varies. Some are relatively strict when it comes to specifying the requirements in the initial phase of the process, whereas others limit the involvement of requirements. Generally, it is again the customer of the consulting companies who directs how loose or strict the requirements are specified. However, the character of the consulting companies also affects how this is done. In the initial part of the process, Company A and E focus on specifying the requirements, while Company B and G instead concentrate on exploring the origin of the customer's idea. Moreover, functional requirements are more prominent than quality requirements at Company A and E. For the product companies, requirements are not a central part of the development process. Both functional and quality requirements are instead mainly found from and incorporated in use cases, personas, and prototypes. Several of the interviewees from the product companies emphasise that the requirements are driven by the needs of the target users. For example, Interviewee H describes that the data that is collected by applying different UX activities is distributed between a number of use cases. Moreover, the quality requirements, that are elicited from the user data, *"completely direct the functional requirements"*. In Company K's case, whose development process is completely directed by UX, the requirements are found in the changes that need to be made in order to improve the UX.

However, Interviewee J mentioned that when it comes to the hardware and electronics, the requirements have been, and must be, defined more strictly. The dilemma of combining the respective development processes for hardware and software was discovered as a recurring theme during the interviews. Company J described this challenge as: *"It's an obvious problem that, in a certain phase of the project, it's somewhat contrarious that [the software developers] want to wait as long as possible with deciding while the [hardware developers] must decide earlier "* To manage the problem, Company J has retained the design on the physical product simple and generic. Interviewee E2 mentioned that *"hardware in an agile process is difficult"*. Company E handles the dilemma by having longer hardware sprints than software sprints. Interviewee D mentioned that it is difficult to update the hardware, whereas software is just a matter of how fast they can develop.

To summarise, all companies apply agile development methods. The consulting companies are similar in the way that they are dependant on their customers' desires and that they adjust their generic development process according to the characterisation of their customer. The characterisation of the development processes at the product companies varies from applying iterative sprints (Company D and J), being directed by UX (Company J and K), to being unstructured and self-organising (Company I and K). The common property among the product companies is that requirements do not constitute a central part of the development process. The requirements are instead integrated into use cases, personas and prototypes. In contrast, the handling of the requirements is something that differs among the consulting companies. Company A and E are more focused on specifying requirements than the other consulting companies, i.e. Company B, C, F, and G. Company B, F, and G collaborate in different ways with their customers in elaborating the origin of the ideas. Finally, Interviewee D, E2, and J identify that there is a challenge related to the IoT development process, which involves combining an agile software development process with hardware development.

### 4.3.2 UX Development

In this section, RQ1 in Table 1.1 regarding how the companies consider UX in their development processes is adressed. First, the companies organisation when it comes to UX is described, followed by a summary of the UX activities that are performed during the process.

#### UX Organisation

The overall organisation at the companies affects how the development from the UX point of view is organised. 10 of the 11 companies consider UX as something that is integrated throughout the whole development process.

Interviewee B and G discuss their whole development processes from a UX development point of view. Interviewee G regards their UX perspective of the development process as the main reason for why Company G's customers hire them. Interviewee B outlines the steps of defining the real problem or challenge, generating concepts or solutions, prototyping, and evaluation. Interviewee C1 describes Company C's process similarly. Additionally, the interviewees mention that Company C develops both the software and the hardware for their customers. It varies between different projects when Interviewee C2, as an industrial designer, is involved in the process. Interviewee C2 is of the opinion that the best way is when the designer is involved throughout the whole process.

When describing their company's organisation, all interviewees except from Interviewee A, F, and I spontaneously describe their teams as cross-functional. Interviewee B argues the importance of cross-functional teams by stating that *"it's not just the designers that design"*. Nevertheless, the interviewee thinks that it is important that the designer takes the responsibility for zooming out to the larger perspective and taking the possibilities within technology, business, customers, and users into account. As both interviewees from Company E describe, their teams in various projects consist of resources from the company's three departments: hardware development, embedded software development, and cloud development. When asked about how UX is included in their development process, Interviewee E1 expresses it as *"it's not like we have any special roles for this in the company currently"*. Instead, it depends on who is involved in the different projects and what their interests are. In comparison, when considering how UX is included, Interviewee E2 answers: *"We must admit that, unfortunately, it is rarely done. Not the way it would be needed. We are pushing more and more for validation, that is to say, testing in the field, but it usually comes in very late."*

Company A distinguishes themselves from the other companies by seeing UX as something that is separate from the rest of the development process. In comparison with Company E, Company A does not have a specific UX department. Additionally, to the interviewee's knowledge, there are no UI design specialists at the company. In the cases where the competence of an industrial designer is required, this person is involved in the process as an external resource. In contrast to how Company A and E are organised, Company F has a UX department which is responsible for the UX development in the different projects. Moreover, there are developers that focus on and have experience from working with UX and usability. Thus, as stated by Interviewee F, *"if the request also concerns taking care of [UX], we will do that"*. In those cases, this is done by including resources from the UX department in the team.

Interviewee H works in *"a UX team of seven people, who supports all ongoing innovation projects"* at Company H. In each project, the members in the cross-functional teams assist in the different phases. At large, their team members either have a background in business, engineering, or design, with a majority of hardware and software developers. At the start of the department, all employees were introduced into a new way of thinking and were encouraged to read literature about the fundamentals of Lean start-up, design thinking, and interviewing techniques. This was to enable the whole team, and not just the UX designers, to do research and conceptual designs and to build prototypes by *"faking the experience"*. However, when it comes to constructing the physical parts of the product, the department is assisted by Company H's industrial design department. There are around eight industrial designers at the department. Since the department *"constantly needs help* *with the industrial design"*, Interviewee H would prefer to have this competence within the department as well.

The UX organisation at the start-up product companies (Company D, I, J, and K), is, from some perspectives, different from that of the other companies. Company D started by developing different parts of the product parallelly. A similar approach was adopted by Company K. Plastic prototypes of the appearance of the physical products were iterated until deciding for a final prototype. Meanwhile, the software was developed iteratively. Company D has had the same hardware since the product release in 2015, but the software is continuously updated. When deciding for how fast new functionalities can be released, Company D applies the concept of minimum viable product (MVP). As stated by Interviewee D, *"the product will never be complete"*. Interviewee J and K express the same opinion about their respective products. Interviewee K says that *"the one thing you can be sure of is [...] if you end up with the product you have had in mind from the start, then you have done it wrong. Then you have missed opportunities of improving"*. In Company K's case, it is the CEO who takes the final decisions, but all employees are involved in all parts of the development. In comparison, the decisions at Company D are taken by involving all employees.

At Company D, one of the employees has the responsibility for UX. For instance, this UX designer creates the experience and sketches how it will appear by using digital tools. Despite having relatively few employees, Interviewee D thinks that *"a key to our success is actually to have a person that thinks about the user experience - who has that role in the beginning"*.

Company J has a UX team, of which Interviewee J is the director. The company has employees of all competence categories that are necessary for developing their product. The production is the only task that is performed by external resources. When initiating the development process, it was mainly done from a UX point of view, with mapping the users and their needs. Interviewee J described their process as consisting of *"much parallel work - defining users and problems and solutions, while also prototyping parts"*. This parallel way of working was built on the thought that *"mechanists and software engineers do not have that much in common but if they start talking to each other and testing something, they may come up with something totally new"*. Nevertheless, the UX team works closely with the software developers. When it comes to the physical product and the hardware, the design freeze point is reached before the software is complete. Therefore, as explained by the interviewee, the interface on the product itself has been retained on a fairly generic design level.

In contrast to that the other startup companies talk about UX in broad terms, Interviewee I refers to how Company I work with the UI when asked about how UX is integrated in the process. From that perspective, the company works with concept drafts where the design of the UI is presented as a screen shot. *"Thereafter"*, the interviewee continued, *"it's up to me or another programmer to try to make it correspond to the visions"*.

## UX activities

In table 4.2, activities mentioned by the companies are listed and categorised as either qualitative or quantitative. Qualitative UX activites are mentioned by all companies except from A and I. Example of such activities are prototyping, feedback from users, user

**Table 4.2:** UX activities

| Company | Category | Qualitative activities | Quantitative activities |
|---|---|---|---|
| A | Consulting | - | - |
| B | Consulting | Prototyping<br>User tests | User data |
| C | Consulting | Prototyping | - |
| D | Startup | Prototyping | Unknown |
| E | Consulting | Occasional user tests | - |
| F | Consulting | Depends on the customer<br>Mock-ups<br>User feedback | - |
| G | Consulting | User research<br>User tests<br>Scenarios<br>Story boards<br>Personas | User data<br>A/B testing |
| H | Product company | Prototype/Simulation<br>End user tests<br>Personas<br>Surveys<br>Interviews with end users | Google Analytics<br>A/B testing |
| I | Startup | Indirect user feedback<br>Conceptual schetches | - |
| J | Startup | User research<br>Feedback from beta testers<br>Personas<br>Focus Groups<br>Shetches | Google Analytics<br>In-house A/B testing |
| K | Startup | User research<br>User feedback<br>Prototyping | Unknown |

tests, focus groups, interviews, and user research. In addition, Interviewee B, G, H, J, and K describe that they are using automatically generated quantitative data, such as Google

Analytics and A/B testing, to evaluate UX.

Extensive user research is foremost described by Interviewee G, H, J and K. Identifying the user and the underlying problem is seen as important. For example, when asked how their UX decisions are made, Interviewee G answers, *"Research! User research. We do a lot of research. Both market research and then concept testing, basically. So we have workshops, focus groups, interviews, just being out watching people, shadowing people, depends on what the context is, but a lot of observation"*. Interviewee J, describes that they have focused on the underlying needs and not the product itself; *"The interaction designers [...] wanted to look at who the users are - what everyday needs do they have, how is their journey through life?"*. Moreover, the interviewees provide some examples of user research activities such as personas, scenarios, story-boards, interviews and surveys.

Interviewee B, H, G, J, and K emphasise the importance of involving the end-users during the development process. For example, Company J has had beta testers using their product, which have provided feedback and analytics data. Company K started by investigating their end-users and their needs. For Company H, including the end-users is essential. Interviewee H sees it as one of their main missions during their projects to go out in the field and talk to the end-users. Interviewee I brings up that they have had people testing their product using virtual reality as a marketing activity. Even though the primary goal was not to receive user feedback, Interviewee I mentions that they received valuable suggestions from visitors during that activity. Both interviewees from Company E believes that involving the end-user would be beneficial for their development process. However, it is rarely done. Interviewee E1 mentions that *"In some cases, it may be that you may have to run some user test to test a hypothesis. But usually, it's enough to use our knowledge, that is to say, previous experiences or [...] for example design guidelines."*. In comparison, Interviewee E2 said: *"In the design process, we have very little user feedback"*.

Prototyping is also something that is emphasised by most interviewees. Interviewee D stresses the use of 3D printing in order to be able to test different use cases early on. Similarly, Interviewee K also describes how they have been testing with prototypes. Interviewee B argues the use of easy and quick prototyping; *"Then you can just test the technology in combination with people's problems which you try to solve."*. However, the interviewee sees a problem with proceeding to generating solutions too quickly, since this involves a risk of losing the underlying meaning.

Several interviewees also mention different kind of software prototyping tools, such as mock-ups, key-note presentations, and movie simulations. For instance, Interviewee D experiences that it is easier to discuss a prototype than requirements, because *"if you take [the prototype] to the developers, then they exactly know what it's supposed to look like"*. Interviewee K means that prototyping the functionality is a good way of determining if the development goes in the right direction; *"It's a very large difference to imagine how something should be and actually make a sketch of it, and even simple stuff like recording a movie [...]. This can give a lot of confidence that you are on a good or bad track."*

To summarise the two sections about UX organisation and UX activities, we have found some similarities as well as some differences between the companies when it comes to how UX is taken into consideration during the development process. Company F, H, and J have a UX department, and the smaller startup companies - Company D, I, and K - each have employees responsible for UX, with the rest of the company still being involved in UX decisions. In contrast, Company A, C, and E do not have anyone internally employed that is explicitly responsible for UX. Nevertheless, most interviewees describe that their organisation is built upon cross-functional teams. Interviewee B and H specifically emphasise that it is not only the UX designers that are part of the UX design work. The extent to which UX activities are exploited is a differing factor, where Company A, C, E, and I tend to apply such activities to a lesser extent. Some of the most common UX activities that the interviewees bring up are, as can be seen in Table 4.2, prototyping, user tests, and user research.

### 4.3.3 Data-Driven Development

In order to explore the topic of RQ2 in Table 1.1, which involves how the companies apply data-driven development from a UX perspective, several questions about the development process, the product life cycle (PLC) management, and the use of data were asked. Different factors that affect the degree to which the companies are able to be data-driven are identified and described.

A summary of updates and development after the product is released to market is presented in table 4.3. It should be noted that companies that work in a more data-driven way do not generally see the product as finished when it has been released to market. For example, Interviewee K said: *"For us, it's not binary. It's not the traditional business mindset that you develop a product for a long time and then you release it and everyone will have access to it at the same time."*. However, we focus on the development after the product is released to the market, and especially how automatically generated data is used. As can be seen in table 4.2, some companies use quantitative measures also before market release.

The consulting companies are dependent on the costumer regarding whether they continue working with the product after it is released to the market or not. This can be seen in Table 4.3. All consulting companies except from Company G offer a service agreement where they are responsible for updates and new releases. How the service agreement or PLC management is set up depends on the customer. For example, Interviewee B says: *"It's [done] in consultation with the customer, it's in fact extending the assignment to be able to provide continued improvements or changes after the product is released to the end-users"*.

Three of the consulting companies (Company A, B, and E) see PLC management for IoT as a possibly new business opportunity. For example, both interviewees from Company E see hosted solutions as a possible future business model. Concurrently, they hold that it would require changes in both their business model as well as organisation. Company G is slightly different since it is a design agency. They have not been a part of PLC management yet but consider it as a future aim.

The product companies are, naturally, responsible for their products even after they have been released to the market. Neither Company H nor Company I have products on the market yet. Company I is still in the development phase and the innovation department at Company H has some products running in pilot installations.

Company D, J, and K all have their products on the market. None of them considers their product as finished and they explicitly describe that they use quantitative data from the product to develop the product also after market release. Company D uses a *"device management portal"*. All new features are pushed out through the portal which also collects data and statistics from the devices. Interviewee D emphasises that the device

Table 4.3: Development after market release

| Company | Category | Responsible for updates or development after market release | UX activities after market release |
|---|---|---|---|
| A | Consulting | Depends on customer agreement | Security updates |
| B | Consulting | Depends on customer agreement | Updates<br>Improvements<br>Customer feedback |
| C | Consulting | Depends on product and customer agreement | Updates<br>New releases |
| D | Startup | Yes | Device management portal<br>Customer feedback<br>New features |
| E | Consulting | No/depends on user agreement | Updates but do not usually follow the product actively |
| F | Consulting | Depends on customer agreement | Unknown |
| G | Consulting | Not yet | - |
| H | Product company | Do not have products released to market | - |
| I | Startup | Do not have a finished product | - |
| J | Startup | Yes | Google Analytics<br>User feedback |
| K | Startup | Yes | User feedback<br>User data<br>New features |

management is closely related to their development and strategy; *"In fact, all data that comes there can be used to create a better product"*. Company J uses Google Analytics data for various purposes, such as finding bugs, determining which functions that are used the most, and evaluating the set-up time. Information that comes from Google Analytics is seen as either a warning that something is wrong or a sign of approval that it works as expected. However, the interpretation still needs to be made. Interviewee J claims that they are, to some extent, immature when it comes to using the data. The interviewee sees future possibilities with collecting other data than just which features that are used. One such possibility could be to extend the studying of behaviour data. In addition, the company is interested in behaviour data that concerns the physical product and not only the software.

When it comes to A/B testing, Company J does it during the development process but not after market release. Interviewee J means that the reason for not applying A/B testing in the field is that they *"don't have that many customers yet. So we dare not risk that one particular solution may be bad"*.

Company K develops new features that are released to a limited number of users. Interviewee K described that when *"The product is out, it's already in thousands of homes. And we can do such a thing as doing a new feature, deploy it to a hundred users, and see if they are using it or if we want to do something more."*.

As the innovation department at Company H do not have any products on the market yet, it cannot be determined if they will collect and analyse data after market release. However, Interviewee H mentioned that Company H at large has used Google Analytics for this purpose for long time. In addition, the department uses Google Analytics in their development process.

Company F manages data for both their own and other's products. It is however unclear if they use the data to improve the product. Interviewee B argues that, in some cases, the product is seen more as a platform or service that is continuously built upon even after market release.

In addition to collecting data of a more qualitative character during the development process, several of the companies also collects this type of data after the products have been released to the market. Interviewee B mentions that they collect data in terms of different kind of feedback from users. In addition to working with Google Analytics, Company J also collects data from social media, support mail, and opinions from beta testers. Also Interviewee D and K describe that they use customer feedback to improve the product. Company A focus on security after the product is released and uses information from data security forums to find security hatches.

When it comes to data-driven UX, some of the interviewees mention that they found it challenging. Most interviewees that say that their company uses metrics related to UX, also argue that the quantitative data can be problematic and need to be complemented with data from, for instance, user tests or feedback from users. For example, as Interviewee G said: *"Of course, there are total numbers [...], so then we know "okay, that's important". We don't know why it's important, though."*. Interviewee H stresses that *"You have to use it with other data. You have to make interviews, and have contact with focus groups also to put it in context"*. Interviewee J sees Google Analytics data as an indication of that something is wrong; *"It's usually just a catalyst, an indication that here's something strange."*

To summarise, the consulting companies are dependent on their customer agreement when it comes to continuing the development after market release. In the product companies' case, they consider it obvious that the development continues also after market release. Interviewee D, J, and K explicitly describe that they use automatically generated quantitative data in order to improve the product also after market release. In addition, Company A, B, D, J, and K applies evaluation of the product after it has been released to the market in terms of qualitative data. Interviewee G, H, and J highlight that this qualitative data needs to complement any collection of quantitative data, in order to find the reason for the indications that are found in the quantitative data.

### 4.3.4 IoT UX challenges

During the interviews, some specific challenges with developing IoT were mentioned by the interviewees. From these challenges, we could identify three themes that are more related to the properties of IoT than the characteristics of the development process; communication, finding the value in connecting things, interaction, and privacy and security.

#### Communication

Most interviewees mention the challenge of communication, for example by discussing interoperabilty, Internet connection, and lack of standards. Interviewee H describes the interoperability issue as *"One very basic thing is something that has been around for a long time, but is still difficult. And that is to connect things to each other."*. Furthermore, Interviewee I argues that *"you have to design in a different way since everything is network based"*.

Interviewee G highlights the user perspective, which involves that the digitised products communicate with each other invisibly, and that it is difficult for the user to know what information that is being shared. Interviewee G considers this as a trap for IoT *"because as soon as you have a digitised product that is communicating with something else, there is invisible communication happening that the user does not really have an intuitive perception towards"*. Interviewee H experiences a similar challenge, which is the problem of knowing that two devices are communicating with each other.

Interviewee H means that UX for IoT can be seen as *"an ecosystem of experiences"* and emphasises that there is a number of factors that affects the experience that cannot be controlled. An example of such a factor is the question of how it works together with other products. Something that is also mentioned by for example Interviewee D, is the problem of being dependent on other systems, such as the user's router or poor WiFi connection. These are aspects that are difficult to influence, but they highly affect the experience of the product. Interviewee K argues that *"The big challenges are when you have to build on systems that are not that good"*. Interviewee I sees it as an issue that it cannot be ensured that there is Internet connection available everywhere. Similarly, Interviewee G mentions reliability as a challenge *"because IoT has this huge promise of everywhere, anywhere, anytime. All of us know that even simple WiFi doesn't work all the time, every time"*. Interviewee E2 raises another related problem; *"If it is an IoT-device, then I must see updated data in my app [...]. It cannot be fifteen minutes old and then it takes ten minutes to update"*.

Interviewee F regards it as problematic when different actors develop their own platforms and standards; *"It will never work that each industry owns whole ecosystems. What is needed is openness and finding standards."*. In accordance, Interviewee G also describes the challenge of compatibility; *"There's so many different solutions, applications out there [...]. There's just no standard"*.

## Finding the Value in Connecting Things

Most interviewees mention that a key challenge is to find the value in connecting a product. Interviewee D, J, and K mean that the definition of IoT itself must include that there is an additional value in connecting the things. Interviewee D states that the purpose of connecting the things must be clarified, by asking: *"What is the new value that you can provide, that hasn't been provided before?"*. Interviewee C1 sees it as that the value is created beyond connecting the product itself and that the value instead lies in the ecosystem; *"[...] you need to build ecosystem[s] to put out the whole value"*.

Interviewee G argues that the focus should be on the user problem that needs to be solved, and added that *"If you have a cool technology and you try to find the problem where you can make it fit, that's often where very dubious value comes to life"*. However, in Company D's case, they started out with seeing the opportunity in their specific technology. The application area and the industries in which they operate and adds value were found afterwards. In contrast to Company D, Company K started with the application area, from which a problem was formulated. For Company I, the idea came from an industrial designer. Interviewee I means that this has resulted in that *"it's the design that has been the central part"* of the development process from the beginning. The concept that Company J is built upon, came from that several of the employees previously had worked with a similar technology, but they thought that it could be done in another way. Therefore, they started by understanding their users' needs related to that technology.

## Interaction

When it comes to interaction, it was mostly the set-up and installation that was stressed by the interviewees, even if Interviewee A and E1 also consider the UI.

To have an easy installation of the device is something that is mentioned by several companies. Interviewee D believes that it is easy to make too advanced services and also that the installation needs to be simple. For example, Interviewee C1 says that they *"call it plug-and-play"*, and Interviewee A expresses it as: *"With a small stupid IoT device [...], you should be able to plug it in and it should work. Anyone should be able to do that by picking it out of the box and starting it"*. Interviewee A argues the importance of being able to easily configure the device, especially if the IoT device itself do not have a UI and needs to be configured by using, for example, a smartphone. Moreover, Interviewee E2 means that the complexity of IoT as well as the communication with external systems make it more difficult to install it in a simple way.

Interviewee E1 mentions that the UI is different for physical products compared to screens. Interviewee I sees the difference as that the interface can be on another product than the product itself, such as a phone or tablet. In comparison, Interviewee A identifies the difference as that an IoT device does not necessarily have a physical UI.

## Privacy and Security

Interviewee F and G describes ethical considerations related to IoT and UX. Interviewee G argues that privacy and security is a UX challenge; *"It's not necessarily a technical challenge, that is a UX challenge"*. Interviewee F stresses the connection between UX and security and means that an easily configured but insecure device results in poor UX. Because, when the user realises that the device is insecure, it gives the user a bad experience. Furthermore, Interviewee G brings up data sharing as a privacy issue: *"I wouldn't want my healthcare data to be connected to everything else in my life"*.

# Chapter 5

# Discussion

In this chapter, the findings from the empirical study are discussed together with the findings from the literature study with the aim of answering the three research questions stated in Table 1.1. Firstly, in section "5.1 UX in the Development Process for IoT", the UX perspective of the development process for IoT is addressed. Secondly, in section "5.2 UX in Data-Driven Development for IoT", data-driven development for IoT is discussed from a UX perspective. Thirdly, in section "5.3 Identified UX Challenges for IoT", the identified challenges when it comes to UX for IoT are discussed. This is followed by section "5.4 Future Work", where we provide some suggestions for future work. Some ethical considerations concerning IoT are given some thought in "5.5 Ethical Discussion". Finally, the section "5.6 Threats to Validity" covers the identified validity threats concerning the literature review as well as the empirical study.

## 5.1 UX in the Development Process for IoT

With this section, the aim is to discuss the first of our research questions, RQ1: "How is UX taken into consideration during the development process of IoT?". This question is addressed in section "3.2.1 Design Processes" in the literature review and in section "4.3.2 UX Development" in the empirical study. Therefore, the focus in this section is to discuss if these results are specific for IoT. This is done by comparing common elements in the literature review and the empirical study.

In the literature, we found examples of how the properties of IoT is thought to change and refine the design processes. Fauquex et al. propose including two additional phases in the UX design process when developing IoT systems [36]. They motivate this extension of the process by referring to the existence of ecosystems around IoT and that it is necessary to emphasise both user and context research even more. Even though that the relevance of context is a recurring theme during the interviews, there are no examples in the results that indicates that this has resulted in a change in the development process. The main difference to the process consists of that the degree of complexity is higher due to that it involves more parallel tracks. Additionally, Interviewee H considers the novelty of IoT as a contributing factor to why the innovation department's development process needs to be of a more innovative character than the process at Company H.

De Haan describes a shift towards more prototype-based, user-centered, and exploratory design processes [41]. As can be concluded from section "4.3.2 UX Development", a majority of the interviewees seems to consider prototyping as a natural part of their process. The use of rapid prototyping, as advocated by Kranz et al. [45], is favoured also by Interviewee B, who at the same time considers it a risk that the accessibility to easy prototyping can cause an undermining of substantial user research activities. The use of different software prototyping tools described by Interviewee D, H, J and K can be seen as confirmatory of the increased use of higher level tools that de Haan brings up. However, end-user development (EUD), which is covered in section "3.2.1 Design Processes", is not given much attention by the companies. Company J uses a mobile application as the interaction agent where it is up to the user to decide which features that should be connected to the physical UI of the product, can be seen as a graphical approach to EUD. Interviewee K mentions that they provide an open application programming interface (API), but, as Barricelli and Valtolina mention as an issue in [38], this requires a certain extent of programming knowledge.

It is most evident from the list of UX activities in Table 4.2 that the development processes of Company G, H, J, and K revolve around user research and involving the end-user. Company C and F imply that they involve the end-users to a certain degree. In contrast, Company A and E do not apply a user-centered approach to any wide extent, but Interviewee E1 is of the belief that it would benefit their development process to do this more. The interest in UX and user-centered activities among the companies could be described by the increased user-centeredness described by de Haan and the general shift towards UX found by Ovad et al. [41] [49].

The increased exploration within the design process is exemplified by de Haan with the use of Living Labs, which also Pallot et al. base their metrics on [37], and the collection of user data, as described by Olsson et al. in [20]. We consider that to complement the qualitative UX activities with collecting quantitative data, as some of the participating companies do, can be an example of how their design processes are exploratory in character.

De Haan also describes that the development processes are becoming more iterative [41]. From our empirical results, it is evident that all companies aim at working agile. Company H describe that the reason for having a different development process at the innovation department was to be able to work more iterative, in faster cycles. One of the reasons was described to be that they are developing for IoT which is unknown ground. Moreover, as is given further attention in the consecutive section, some companies have adopted a data-driven approach to their development process. According to Olsson et al. [18], this is an example of how their processes are even more iterative in character than an agile process.

Irrespective of the reason for applying an agile development process, it is, as Interviewee D, E2, and J explain, difficult to combine an agile software development process with hardware development. This is highlighted by Rowland et al. as distinguishing for IoT development [30]. However, only Interviewee D, E2 and J address this hardware-software-dilemma. This might indicate that the extent to which this dilemma affects the development process is in practice not considerably large. One reason for that the interviewees do not emphasise the dilemma may be that, as also mentioned by Rowland et al., the degree of visibility of the device and the frequency of interaction with the device affect how the physical design is constructed. For example, the physical products of Company D and K are neither meant to attract attention nor to require the end-users to interact with them. Most of the companies' products use mobile agents or web-based UIs. This is the case for Company D and K as well. In all, this makes the essential functionality of these IoT systems less dependent of the physical device. Instead, they rely on that their specific technologies, that has been built in from the beginning, can perform their specific tasks. On the other hand, Company J has a visible physical product with which the users can interact and thus making it more dependent on the physical UI.

The combination of hardware and software development is not a new challenge. For IoT, as formulated by Rowland et al., the distinction from other systems is exemplified by that there are *"few established device archetypes or category conventions"* [30]. We think that this may increase the risk of aspects arising during the software development process that require hardware changes. Such changes can be both time-consuming and expensive to conduct. To avoid this situation, we consider it important that extensive research and prototyping is performed early on in the process, with respect to both hardware and software.

Even though that there are examples among the companies that indicate that their design processes are both prototype-based, user-centered, exploratory, and iterative, it is difficult to say, based on our results, that these characteristics of the processes due to that the companies specifically develop IoT. We believe that there are other characteristics of the companies and the products that they develop that affect the processes. A more user-centered approach can be the result of that some companies develop consumer products whereas others address other businesses as their customers or develop systems for industrial applications. As an example, Company D do not involve their end-users to the same extent as Company J and K, for which a reason might be that their customers are other businesses and not the end-users. Moreover, the consulting companies depend more on their customers than the end-users, which differs from the product companies. For instance, Company F has a clear business perspective irregardless of what kind of product they develop. The age of the company might also contribute. Additionally, the examples of development processes among the companies that are highly iterative, can also be due to that they are adopting the general trend of increasing agility rather than adjusting to specific characteristics of IoT development.

Our results imply that the distinguishing part of the development process for IoT comparing to other systems is that the combination of hardware and software development becomes more evident. However, the degree to which this affects the development process is dependant on the product. We agree with Rowland et al. that the more visible the device is and the more interaction that is required, the more impact will this dilemma have on the development process.

Consequently, there are varieties in business models as well as company and product characteristics, which, presumably, is independent of that the companies develop IoT. We do, however, believe that IoT development requires an agile development environment. According to Olsson et al., a key to be able to apply agile principles is to work in cross-functional teams [18]. The diversity of IoT results in that professionals with background in several disciplines meet; hardware development, software development, industrial design, and interaction design are some examples of these disciplines. Therefore, we think that cross-functional teams are especially important in the context of IoT. It is something that all companies apply, even though that the way it is done varies. From a UX perspective, an industrial designer may have another way of defining UX than a software developer, but with IoT, we believe that a collaboration between them is needed and requires that they are working in the same direction, towards the same goal.

## 5.2 Data-Driven UX Development for IoT

In this section, we address the second research question, RQ2: "How is data-driven development from a UX perspective applied within IoT?". First, we attempt to explain why some of the companies apply data-driven methods and some not. This is done by referring to a study by Olsson et al. [18], where the different steps a company goes through on their way to a data-driven approach are described. The reason that we choose to use the theories from Olsson et al. is that they have contributed with several articles in the field of data-driven development. After that, the focus is on the companies that apply data-driven activities either during the initial development phase, after market release, or both.

Going from traditional development to agile is described as the first step towards data-driven development by Olsson et al. [18]. Company A and E do not mention any data-driven activities when it comes to UX. The interviewees from both these companies describe that they apply an agile development process, but that they focus on requirements in the beginning of the process which is a main barrier for applying the agile principles entirely according to Olsson et al. [18]. The main reason for consulting companies to focus on requirements is probably that they often are formulated together with the customer to ensure that the products they develop coincides with their request. A barrier towards data-driven development according to Olsson et al. is to not have a base product to continuously develop and improve, which also apply to the consulting companies. However company B and G are both consulting companies that describe that they apply data-driven activities to some extent during the development process. Company B is a consulting company that apply some data-driven activities, foremost in their development process. In Company F's case, it is difficult to determine to which extent they apply data-driven methodologies. We assume that the reason is that the company is large and regulated by what their customers request. A reason for that Company A and E tend to focus more on the requirements could be that they are both older than the other companies and that they have their background in more traditional product development with a hardware focus. The different culture within hardware development and software development is also a barrier towards data-driven development described by Olsson et al [18]. It can be concluded that the consulting companies have problems in applying data-driven development. However, it is beyond the scope of this thesis to discuss if the consulting companies would benefit from data-driven development or not.

Company J and K have applied data-driven UX activities both during the development process and after the product was released to the market. Interviewee D did not know if a data-driven approach was applied before their product was released to market. However, Company D applies post-deployment data-driven UX activities. None of the three companies consider their product as finished. In addition, they have some things in common. Firstly, they have a product released to the market that they collect data from. Secondly, they have an organisation where UX, software development, and product management are closely integrated. Olsson et al. emphasise that a key challenge with applying continuous development of the product is that the R&D organisation and product management need to share the same goal [18]. In fact, Interviewee D has a role at the company that aims to connect development, sales, and marketing. Also Interviewee K describes that sales and marketing are closely related to the development process. Even though that Company J is larger in size than the other two, Interviewee J similarly describes that UX designers, developers, and sales collaborate. Company H does not have a product released to the market yet, but Interviewee H describes data-driven activities during the development process. Since Company H is a department at a company with strong traditions of using automatically generated data to improve their products also after market release, we assume that this will be the case at Company H as well.

Company D, J, and K have products that automatically collect data, which according to Olsson et al. is a prerequisite for applying "R&D as an innovation system" and thus, to have a data-driven development process [18]. The second prerequisite is that the R&D organisation must be able to make use of the data in an efficient way. Among the companies that collect automatically generated data, it is common to use usage data in terms of evaluating to which extent the different features are used. This is also mentioned in another study by Olsson et al. [20], where they describe a proposed framework for post-deployment data usage. Foremost Interviewee K mention that they experiment with features, for example by deploying updates to a limited group of users. This is also something that Olsson et al. bring up [20]. Interviewee D and J do not describe specifically that they experiment with, for example, new features after the product is released to market. However, Interviewee J mentioned that they did A/B testing during the development process when they used in-house beta testers. Now, Interviewee J mentions that due to that they still have relatively few users, they cannot risk providing some of them with a version of the software that is less satisfying for the users. Nevertheless, both Interviewee D and J are convinced that they can make better use the collected data to improve the product.

One thing that most of the interviewees in our study bring up is that the quantitative usage data is difficult to interpret without qualitative data. The interviewees consider that the usage data itself does not tell anything about the underlying reason. Therefore, the interviewees propose that the quantitative data should be used together with qualitative data in order to understand, for instance, why a feature is used or not. In [19], Olsson et al. conclude that qualitative and quantitative data do not always coincide. From this study, we interpret that Olsson et al. are of the opinion that the quantitative data is more reliable. However, in [63], Olsson et al. propose a model where both qualitative and quantitative data is used to continuously evaluate hypotheses instead of defining requirements. This is more in line with the way the companies participating in our study use quantitative data.

De Haan [41], believes that the data-driven approach presented by Olsson et al. is problematic if it is applied without *"proper and creative interpretation"*. De Haan means that *"the process may simply lead to the most average HCI design ever created"*. Since the results from usage data from one perspective represent the average use of the system, it also represents the average user. To have this data lead the innovation may make it difficult to create innovative and creative products. It is also possible that the relatively unexplored field of IoT requires more creativity and innovation since there is a fewer number of applications to copy or take inspiration from. On the other hand, this can also motivate to perform more experimentation with, for example, new features. However, the interpretation still needs to be made to be able to use the data to improve the product. Some companies in our study describe that they use the quantitative data as an indicator but that they still try to make an interpretation of the data not only by experience but also by using qualitative data. Law et al. [64] emphasise that it is essential to both understand why UX measures are taken and also to interpret the results in order to use it for design and development decisions. In addition, Law et al. list both advantages and disadvantages with qualitative and quantitative data. As an example, qualitative data is seen as useful in order to generate alternative design ideas whereas quantitative data is easier to use in order to convince decision makers [64].

## 5.3 Identified UX Challenges for IoT

In this section, we discuss RQ3: "Are there any specific UX challenges that need to be considered during the development process for IoT?". The challenges that were identified in the empirical study were presented in section "4.3.4 IoT UX Challenges". Therefore, this section is aimed at connecting the identified challenges with the distinguishing properties for IoT that was covered in section "3.2.3 Distinguishing Properties for IoT" in the literature review. First, challenges related to communication is discussed in section "5.3.1 Communication". In section "5.3.2 Finding the Value in Connecting Things" challenges related to value creation for IoT is discussed. Section "5.3.3 Interaction" covers interaction related challenges and section "5.3.4 Privacy and Security" address UX challenges associated with privacy and security.

### 5.3.1 Communication

Drawn from the results from both the empirical study and the literature review, it can be concluded that in the context of IoT, communication is a challenge in several ways. Firstly, an IoT device is always dependent on a network. This network may be of varied quality and will therefore in turn affect the quality of the Internet connection of the device. As expressed by Interviewee D, this is something that is out of the company's control, but it will still affect the UX of their IoT device. As mentioned by Rowland et al., users do not expect *"internet-like glitches from the real world"* [30]. Rowland et al. also mean that physical objects are expected to respond immediately whereas a delay or failure when visiting a web page is accepted to a wider extent [30]. Furthermore, a disconnection may cause the device itself to act on old and invalid data, and the user may be unaware of that the device has become disconnected. As a result, it is difficult to communicate to the user whereas the data is updated or not, which was mentioned by Interviewee E2 and H. If the user finds out that the data is not updated, that could probably result in less trust in the system and a worsen UX. Worth mentioning is that for critical systems within for example healthcare and security, this aspect becomes even more important in the way that the UX harm may be even more severe if the users cannot trust that the system is updated.

If the device also depends on additional systems, such as other IoT devices, interoperability issues may arise. The lack of standardisation is an example of such an issue. This is brought up by Interviewee F and G during their respective interviews, and it is also discussed by Rowland et al. [30]. Moreover, interoperability issues are considered as a main IoT usability criteria by Thomas et al. [55]. Thus, if the goal is to realise an ecosystem but these issues are not taken into consideration, it compromises the usability of the IoT system and in turn, the UX. When the development of an ecosystem requires different industries to collaborate, it is an obstacle that, as Interviewee F described, separate industries wants to own the ecosystem. A collaboration requires standardisation, but presumably, the reverse relationship - that standardisation requires collaboration - is also a premise.

### 5.3.2 Finding the Value in Connecting Things

Rowland et al. use the idea of value propositions and that they should drive UX [30]. As mentioned by Garrett [9], the notion of value creation is a core part of the whole UX design process and one of the main aims of applying the different UX activities. Thus, it is not a challenge that is specific for IoT. The difference in developing for IoT is that there is an additional property to the device that can be made use of in order to add to the value. In turn, this property enables other, new functionality and extended possibilities regarding what the device can be able to perform.

From our results, it is clear that the interviewees consider that the property of being connected to the Internet, results in that IoT development involves a challenge of ensuring that additional value is created with the IoT system. Several of the interviewees consider it a risk that this opportunity is overused. That is the case when this property has been added without paying any attention to if this provides additional value or not. As mentioned by Interviewee D, a customer will not pay for a more expensive product if the additional value cannot be understood nor experienced. Thus, the connected product must come with certain advantages that its unconnected equivalent does not. According to the opinions raised in the results, the additional value can arise from both the Internet connection itself as well as the ecosystem that the connection enables.

The question is therefore where the value of the IoT systems can be found. Is it, as several of the interviewees mention, in the Internet connection itself, or, as mainly the interviewees from Company C touch upon, in an ecosystem of connected things?

In the first case, the mission to find the value can consist of connecting everyday things that the end-users in general do not expect to be connected. This is for example mentioned by Interviewee J, who points out that part of the value of their product consists of having a connected wearable that does not physically appear to be smart. This comes, however, with a problem that Kranz et al. mention, which involves the difficulties in communicating the additional value to the user when the augmentation itself is hidden to the eye [45]. The value can also be found in that the connection to Internet may result in the development of completely new products that would not exist if it were not for this specific characteristic. That is the case for the products of both Company D and K.

In the second case, the presumption is that the value is experienced mainly when the products are part of an ecosystem. The vision of creating an ecosystem of IoT devices is questioned by Interviewee G. Moreover, there are no examples in our results of that the value of the companies' products reside in that it is part of an ecosystem of various

IoT devices. However, Interviewee I gives an example of that it might indeed be a future aim of creating value in having their product as part of such an ecosystem. Even if the interviewees from Company C could not reveal any example of specific products that they have developed, they think that the ecosystem yields the core value of IoT. In accordance, the study by Olsson et al. [44] revealed that the participating companies in their study even considered the creation of ecosystems as critical for adding user value. Hsu and Lin [48] showed that network externalities had significant impact on the user's perceived benefit and adoption of IoT which may motivate the vision of creating ecosystems.

### 5.3.3 Interaction

In the context of interaction, the most distinguishing theme from the interviews was that it must be effortless to configure the devices, irrespective of it involving one specific device or attempting to connect devices to each other. This is not a specific IoT challenge but as the devices may not have a traditional UI, the installation process is possibly more difficult for IoT devices. In addition, the device may be part of an ecosystem of devices which can make the configuration even more complex.

Apart from the installation, the interviewees mostly discuss human-thing interaction from a mobile application perspective. Using an agent to enable interaction with IoT is also described by, among others, Leminen et al. [33]. One challenge with mobile applications is that having many devices leads to a large number of various apps. This is related to the discussion of generic versus specific applications which is brought up by Kranz et al. and Rowland et al. [30] [45].

Other human-thing interaction models, such as voice and gestures, are frequently discussed in the literature but was not emphasised by the interviewees. A reason for this can be that the technology that enables other kinds of interaction is not yet good enough to be considered by commercial companies. An additional reason can be that such interaction models are not yet established among users.

The literature also covers thing-thing interaction and human-human interaction. When it comes to the human role and thing-thing interaction, Interviewee G brought up that it is difficult to communicate to the user that devices are interchanging information with each other. Cervantes-Solis et al. [47] describe that humans can either evesdrop on the communication or be a part of it. When things communicate with each other, there is a risk that the human is left out and feel out of control of the system, which is something that both Olsson et al. [44] and Rowland et al. [30] emphasise. They argue that closed ecosystems hold the users out of control of the system. We consider this has a negative effect on UX. This is thus a new interaction design challenge that needs to be addressed when developing devices that communicate with each other.

As IoT enables, and in some cases even requires, new ways of interacting, we believe that there are several interaction challenges. However, for the interviewees, it seems to be obvious that the interaction is enabled by using the smartphone as an interaction agent. In those cases, the challenge becomes less IoT specific, which means that already known interaction principles can be used.

### 5.3.4 Privacy and Security

Even though privacy and security are two of the most researched areas within IoT, it is hardly discussed from a UX point of view in the literature. In the interview study, Interviewee G brought up security and privacy as a UX challenge and highlighted negative privacy aspects related to sharing for example personal health data. According to Oh and Lee [43], sharing personal data is twofold; on the one hand sharing personal health data with a community is shown to have a positive effect on engagement; on the other hand, personal data is a privacy concern. A precondition for that sharing data in communities can provide additional value, is most likely that the users are aware of what data that is being shared and to whom. Otherwise, there is a risk that people feel monitored in a smart environment. For example, Company D addresses this risk by applying edge processing. In that way, the sensor only sends information from the collected data and not the actual data itself. However, they experience that it is a difficult task to communicate that they do not store any of this personal data.

Rowland et al. mentioned a trade-off between usability-security trade-off [30]. Moreover, according to Hsu and Lin [48], information privacy is a factor for continued use of IoT services. While none of the interviewees brought up the usability-security trade-off, Interviewee F mentioned that a low security level can have a negative impact on UX. We believe that the reverese also may apply; it is possible that a high security and privacy level can have a positive effect on UX.

## 5.4 Future work

Drawn from the structure of this study and the results from both the literature review and the empirical study, we have some suggestions for future work.

This study was conducted in a relatively limited geographical area. It would therefore be beneficial to extend the study into including companies in different areas of Sweden as well as outside of Sweden. Since IoT is in itself a broad concept which covers a number of industries, it would also be interesting to, based on our findings, conduct a similar study that includes companies from different kinds of these industries. In that way, characteristics within industries such as automotive, energy, and healthcare can be studied and compared. In addition, it would in such a study be advantageous to interview several persons at each company. Moreover, a comparison between these IoT companies and companies that develop other software systems would be beneficial to do in order to evaluate the IoT-specific characteristics when it comes to UX development. It would also be interesting if any of these qualitative studies were complemented with a quantitative approach, such as using a survey.

A further investigation into how different companies address the hardware-software-dilemma would be necessary to conduct in order to be able to decide if this challenge is indeed more difficult to handle in the context of IoT. Moreover, suggestions of how this dilemma could be addressed and how companies can work with it during their development processes would be advantageous to identify.

Another topic that can be further investigated, is the relationship between UX and the challenge of security and privacy in the context of IoT. This is something that, to our knowledge, there is little research on. We suggest future work beyond the usability-security trade off that is discussed by, among others, Rowland et al. [30]. Such a study could focus on the question if a high security and privacy level can have a positive impact on UX when it comes to IoT.

One interesting question that arises in the context of data-driven development, is how this approach to the development process affect the creativity when it comes to UX. As the quantitative measures becomes increasingly popular, it would be interesting to investigate in the hypothesis by de Haan; that having quantitative data direct the UX will lead to average HCI design [41].

In the context of data-driven development, it would also be valuable to study how the consulting companies' business models need to change in order to be able to extend the inclusion of data-driven approaches in their development processes.

It was found that the companies did not consider different interaction models than using a smartphone as agent. A future case study could be conducted with the focus on interaction and answering if and why the companies seem to prefer using apps instead of more innovative interaction solutions.

## 5.5 Ethical Discussion

The ethical discussion is divided into two parts. In the first part, some ethical perspectives of IoT in general is described and discussed. In the second part, the characteristics of this thesis are concisely considered from the ethical point of view.

### 5.5.1 Internet of Things

We consider that the main concern when discussing IoT from an ethical perspective, is the data processing and sharing that IoT enables and also requires. We therefore extend the discussion in section "5.3.4 Privacy and Security" by viewing it from the ethical point of view. As mentioned, there is a risk that, if it is not clear what type of data that is being shared and to whom, the collection and exchange of data make people feel monitored. One of the reasons for why this affects the UX negatively is because it trenches on people's integrity. The closer the society comes to the vision of the smart ecosystem, the more will this risk increase. An environment that is constantly aware of the people in it also contributes to the feeling of being constantly connected and reachable. Depending on how the data is used and to which extent it can be accessed by the people, it can make people overly aware of their way of living and their habits. A quantification of people's lives may have psychological effects with increased stress levels and cognitive overload.

The EU General Data Protection Regulation (GDPR) that will be enforced on 25 May 2018 is designed *"to protect and empower all EU citizens data privacy"* [65]. Some of the main changes that GDPR consist of is that all companies that collect data must clearly state a purpose for collecting this specific data; it must be as easy for the users to opt out of sharing their data as it is to accept it; and if the user opts out, the measures of eliminating this data must be built into the systems from the beginning. These requirements result in increasing costs for many companies, especially if the infrastructure for destroying data has not been prioritised before. However, from an ethical and UX perspective, we consider this as being greatly positive changes. It increases the awareness among users regarding what conditions they accept when they start using new applications and systems. Moreover, the users can be more comfortable in knowing that the data will only be used for the purposes they have approved of.

An additional perspective of the ethical considerations, is that it can be discussed if the increased presence of IoT might widen the gap between technology interested users and users with less technical experience. Could people who does not adopt to and embrace a smart environment perceive it as being left out of the system and feel completely out of control? On the other hand, there might not even be choice whether to be a part of it or not, but we do not consider that being ethically defensible.

On the other hand, it could be argued that the diversity of IoT may enable developers to adopt devices to a wider spectrum of users. In that way, IoT can instead bridge the existing technology gap among people and making the technical development to shift towards being more inclusive and accepting to people's differences. In other words, could IoT in fact decrease the technical inequality?

### 5.5.2 The Empirical Study

The ethical considerations were taken into account when formulating the empirical study. The results were anonymised in order to not be traceable to either the interviewee or the company that they represented. Nevertheless, to completely anonymise the companies is difficult since a description of their organisation and industry is needed to make the results comprehensive. However, in this case we consider that the information is not of a character that will harm the companies.

## 5.6 Threats to Validity

There are some threats to validity in the execution of the literature review and the empirical study that ought to be taken into consideration. The limitations in the literature review mainly concern the defining of the search strings, but publication and selection bias are also discussed. These are outlined in section "5.6.1 Defining the Search Strings" and "5.6.2 Publication and Selection Bias". The threats to validity concerning the empirical study are discussed in section "5.6.3 Empirical Validity".

### 5.6.1 Defining the Search Strings

When we defined the search strings, it proved to be difficult to construct them in a way that revealed relevant articles without including an abundance of articles that did not relate to the studied subject area. This is the reason for using more than one search string. Additionally, the search strings do not include any synonyms associated with the concept of IoT. Such terms can be "ubiquitous computing", "pervasive computing" [30], "cyber physical systems", or "wireless sensor networks" [22]. We noted that the research within this area is limited, which could be an argument for including synonyms. During the initial attempts to find the most suitable search strings, we included a variety of synonyms and combinations of those. Unfortunately, the issue of obtaining results with too many non-relating articles was repeated, and very few articles were judged to be relevant for the scope of the literature review. There is still a risk that the omission of synonyms may have resulted in a clustering of articles, and that there are other clusters of articles that have been missed.

We regarded this risk as an additional motivation for conducting the snowballing, since it was assumed that the literature that was missed due to not including the synonyms would be found from the references used by the articles in the start set. As previously mentioned, this assumption was also the basis for only including articles from 2010 and onwards. Consequently, an objection to both of these limitations is that this assumption may not be valid. It is difficult to tell if the snowballing from a conceivably clustered start set widens the search area enough to assume that all other relevant literature was found. Since a complete SLR is not the aim of this thesis, we have not investigated in the validity of these assumptions further.

### 5.6.2 Publication and Selection Bias

Publication bias is an effect of the fact that the results from any study are more likely to be published if the results are positive rather than negative [34]. Since the literature in this review mainly consist of articles with a procedural and organisational point of view, where our focus was on publishing descriptive results rather than on positive or negative results, we think that publication bias has had little effect on the results of the literature review.

Selection bias can have affected the literature review since it was conducted by both authors. This could have yielded an uncertainty regarding how each article was assessed. An additional, possible contribution to the bias regards the fact that the four databases were divided between the two authors. This meant that only one of the authors made the initial selection from the respective databases. To reduce this effect, each article that there was any uncertainty about whether to include or not, was instead discussed between both the authors. Moreover, the same author never read the same article twice during the selection procedure. In specific, this meant that all articles that were selected from the assessment of title, abstract and keyword by one author, was read in its entirety by the other author in the full text exclusion round. This is thought to have reduced the selection bias by enabling both authors to study all the selected articles, to a certain degree. The selection bias in the initial selection of articles cannot yet be rejected.

The small degree of inconsistency in which topics that were included and excluded at the different search occasions, can also be seen as a contribution to selection bias. As can be seen in Fig 4.1, six articles were included during the additional search. Four of those articles ([51], [52], [53], [54]) cover the topic of interaction. Thus, it would have been preferable to also include interaction in the systematic literature search. However, we made an active choice not to include interaction in the search stings since this yielded a large number of articles where only a small amount were related to UX. In a second iteration, this may still have been a topic of interest to include, but this is beyond the scope of the thesis.

### 5.6.3 Empirical Validity

Conducting an empirical study involves a number of threats to validity, which will be discussed in this section. The threats regard both general aspects which always must be taken into consideration in any type of empirical study, as well as limitations that regard this study in particular. The threats to validity are discussed from an *empirical validity* point of view, which involves construct validity, internal validity, external validity, and reliablity [57].

The importance of *triangulation* can be considered with respect to both observer triangulation as well as data triangulation [59]. Observer triangulation has been addressed by the fact that analysis of the data from both the interviews and the literature were performed by both authors of this thesis. However, despite the observer triangulation there is a risk that results that confirms the literature review was unconsciously preferred when extracting data from the interview transcripts. When it comes to data triangulation, it has been addressed by performing both a literature review and an empirical study. In that way, these methods have been used as a way of addressing the aim of building a comprehensive picture of the subject area.

The *construct validity* regards aspects of if the study, as it was constructed, actually answers the research questions. A threat to this validity can be that the interview questions are not interpreted by the interviewees as the interviewers intended. This was addressed by commencing each interview with asking the interviewee to define the concepts of UX and IoT, respectively. When summarising the answers, we used these definitions, together with the role of interviewee, to judge from what point of view the development process had been described.

At most companies, except Company C and E, only one interviewee was interviewed. This could also be a threat to the construct validity. It causes an uncertainty whether the described methods is how the company actually work or how they *want* to work. To avoid this threat, it would have been preferable to interview several persons with different roles at each company. At Company E, two persons was interviewed independently. The answers from the two interviewees were not completely coincided, which further motivates interviewing more than one person. Worth mentioning is that Interviewee C1 and C2 were interviewed together, which most likely affected their answers. In this case, it would have been preferable to conduct two independent interviews instead.

An additional threat to the construct validity could be the semi-structure of the interviews. In some cases, an open question was used where it may have been preferable to use a closed question. For example, the question about UX activities was an open question and we did not ask the interviewee to list any activities in particular. Therefore, it cannot be concluded that an activity is not applied at the company just because the interviewee did not mention it. One approach to address this could be to perform data triangulation by base it on a combination of qualitative and quantitative methods [58], or to conduct both interviews and a workshop [59]. For instance, it could have been suitable to complement the question about which UX activities that are applied on each company with a quantitative questionnaire.

Validity threats that concern the study design are encompassed in *internal validity*. The focus is on whether the results in reality follow from the data, or if there are any other influencing factors. In our case, the internal validity foremost regards the interview situation. One such threat is that the interviewee's personal opinions may not represent the company's. In that way, the answers could possibly be more related to the person than the company. Moreover, the interviewee's role can be assumed to highly influence the answers and how much the interviewee knows about the subject in question. *Confirmation bias* is another example of a threat to the internal validity which can have affected the results. This is due to the fact that during the interviews, we may have been more inclined to ask follow-up questions when the interviewees gave an answer which confirmed our theories.

The *external validity* regards the aspect of the extent to which the results are generalisable. With the exploratory character of this study, it was an aim to receive as much of a comprehensive insight into the subject area as possible. Thus, a threat to the external validity can be the *sampling bias*. Firstly, only Swedish companies from the area of Lund and Malmö have been included. It is also possible that companies or persons that are particularly interested in UX also are the ones that have accepted the invitation to participate in the study. Furthermore, only one larger product company was interviewed. The results are thus based mostly on consulting companies and start-ups. To achieve a more complete picture, it would have been preferred to include additional larger product companies.

The degree of *reliability* depends on how much the data and the analysis depend on the ones who have conducted the study. The main threat to this validity concerns the fact that the coding was not performed optimally. When the results were to be compiled from the tabulated and coded transcripts, we discovered that the way that the codes had been defined were too general. The coding was mainly helpful in creating a general picture of each interview and to identify succinct quotes. This limitation is presumably due to the authors' inexperience with conducting qualitative studies.

Most interviews were held in Swedish, except from the two at Company C and G which were held in English. We consider this a threat to the reliability in the way that information and meaning can be lost or changed due to the translation of quotes from Swedish to English. The translation has, to limited extent, also involved rephrasing and shorting some of the quotes, which may also contribute to this threat. However, in the cases where this has been done, we have considered it necessary in order to emphasise the core meaning of the quote. Moreover, this was done with the context of the quote in mind, which we believe decreases the impact of the threat.

# Chapter 6
# Conclusions

An extended reasoning around our research questions, has lead us to formulate a number of conclusions related to the UX perspective of development process, data-driven development, and challenges within IoT.

There are common elements as well as differences in the participating companies' development processes. It is evident that UX is a main factor of the development at the product companies, whereas the extent to which it is considered varies more among the consulting companies.

Some companies show characteristics of being prototype-based, user-centered, exploratory, and iterative, which coincide with the findings from the literature review. However, these characteristics cannot be explained by the fact that the development involves IoT. In contrast, the combination of hardware and software development is something that presumably becomes more distinguished when it comes to IoT development. This also affects how iteratively it is possible to work with UX, since the hardware development requires making earlier decisions compared to the software development. To be able to minimise negative consequences of this dilemma, we suggest extensive user research and user focus early in the process.

The consulting companies in our study adopt data-driven methodologies to a lesser extent than the participating product companies. Given the traditional consulting business model where customers regulates the development and holds the responsibility of the final product, this is not a surprising result.

Furthermore, it is clear that IoT enables collecting and processing of data, which makes it suitable for applying data-driven development. However, it is not evident that it is preferable from a UX point of view. We emphasise that to be able to interpret the quantitative data, it should also be combined with qualitative data.

The dependency on other systems is probably one of the most difficult challenges to solve when it comes to UX for IoT. If the IoT system is dependent on inaccurate systems, this will negatively affect UX. Furthermore, standardisation and close collaboration between industries is important in order to achieve a satisfactory UX. The lack of standardisation also influence the interoperability, which is a large issue when it comes to enable communication between devices.

One fundamental discussion is how to find value in IoT applications. A contributing part to the difficulty of finding value in the creation of smart ecosystem are interoperability issues. Thus, the present focus of value creation seems to regard finding the value in connecting separate things to the Internet.

When it comes to interaction, one of the main differences between the literature review and the results from the empirical study appeared. Whereas different interaction models such as speech and gestures were frequently discussed in literature, the interaction was foremost discussed from a mobile agent point of view by the interviewees. When applying mobile agents, the interaction challenge, and thus, interaction related UX issues, are not likely to be unique for IoT.

When discussed from a UX perspective, privacy and security are mostly seen as aspects that, if not satisfactory, have a negative effect on UX.

Due to the novelty and width of IoT, neither the whole value nor how the development processes, business models, or users will be affected has yet been shown. Most discussed UX challenges are of a technical character, and can thus not be solved only by UX designers. Therefore, we are of the opinion that cross-functional teams are essential in addressing the challenges. In addition, IoT does not just require collaboration between different professions. To be able to understand the whole value of IoT, we believe that the collaboration must extend to include not only different disciplines, but also companies and whole industries.

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# Appendices

# Appendix A
# Interview Instrument

Characterization

1.1. **Tell us about the company and your position at the company**

- Your responsibilities
- What is your role in the development process for IoT?
- For how long have you been working with IoT?
- When did the company start working with IoT?

1.2.1 **Tell us about your products**

- Customers, end-users

1.2.2 **Tell us about some project(s) where you have been working with IoT.**

- Typical customers, end-users

Process/UX

2.1 **Can you define the concept "IoT"? What does IoT mean to you?**

2.2. **Tell us briefly about your development process for IoT**

- Steps/activities
- Development method
- Do you think that the development process is different for IoT? In what way?
- Are you working with quality requirements/non-functional requirements in your development process?

2.2. **What does "user experience" mean to you (not in the context of IoT)?**

- Which qualities/characteristics are most important when it comes to UX?

2.3 **Would you define UX differently in the context of IoT?**

- Are the characteristics prioritised differently? Are there any additional characteristics that you need to consider?

2.4. **Describe how you are working with UX in the development process for IoT?**

- When in the process are you working with UX?

- What does the organisation look like when it comes to UX, which roles are there? (Does UX work together with others or is it a separated department, are there people that exclusionary work with UX.)

  *(Om litet företag)* Who is responsible for UX?

- How much resources are spent on UX-development and evaluation? At which part of the process are these resources spent?
- What kind of activities are carried out?
- How are decisions made for UX? On what basis are the decisions made?
- Are you using data from the product to evaluate UX in the development process? What kind of data?
- *(Om konsultföretag)* Is the way you are working with UX different for different industries?

2.5. **What challenges have you experienced when working with UX for IoT?**

<u>Data-driven development</u>

3.1 **Describe what happens with the product after it has been released to the market?**

- Who is responsible for new updates and releases?
- How often is the product updated?
- How much resources are spent on the product after it is released to the market?

3.2. **Do you collect data from the product/products to make decisions or to improve the product (this does not have to concern only UX)?**

- What kind of data?
- Do you use data to improve the product after it has been released to the market?
- In what way do you think that you as a company will work with data in the future?

3.3 **Do you somehow use data from the product to develop or evaluate UX in specific?**

- What do you measure?

- How do you measure it?
- Do you carry out some kind of experiment in the context of UX (for example A/B testing)?
- How is the result used (results either from the experiment and/or data collection)?
- Is there anything else that you would like to measure?

3.4 **Is there anything specific in your development process or organisation that makes it easier or harder to use data to make decisions or to improve the product?**

3.5 **Is there anything else that you would like to add?**

# Appendix B

# Informed Consent

## Informed Consent for Participation in Interview Study

I hearby approve of participating in an interview study as part of a Master's thesis at RISE SICS.

I am fully aware of that...

- I can at any time withdraw my participation without having to specify the reason.
- I can choose not to answer a question without having to specify the reason.
- The results from the interview will be anonymised and will not be traceable; neither to me as a person, nor to the company.
- The interview will be documented according to the attached information sheet.
- This form will be established in two copies, of which I retain one and the other will be stored securely at RISE SICS.

Responsible for the interview:

Johanna Bergman
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mte12jbe@student.lu.se

Isabelle Johansson
+46708685152
mte12ijo@student.lu.se

Location, Date

______________________________

Signature

______________________________

Print name

______________________________

## Information about the study

The interview study is a part of our Master's thesis at Swedish ICT (SICS), which is part of the Swedish research institute RISE. The majority of the projects conducted at RISE SICS Lund concerns security and privacy within IoT.

### Objective

The aim of the thesis is to investigate how User Experience (UX) is considered during the development process and product life cycle of IoT devices.

### Documentation

The interview will be audio recorded and transcribed. Recordings and transcripts will be stored securely at RISE SICS. Transcripts will not be published in its entirety. All published information will be anonymised and not traceable to neither you as a person, nor to the company.

### Complementary information

If we realise later on that some complementary information or clarifications are needed, we may contact you.

### After the interview

You will be invited to participate in a workshop aiming to provide new insights in the area of UX and IoT. You will naturally also be provided with the final report.