Cross-Device Interaction With Meta Spaces

Designing Meaningful Interaction with Building Information Models across Devices

Master's thesis in Interaction Design and Technologies

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Abstract

The one user one device paradigm has been prevalent since personal computers became readily available. While there are mentions of cross-device related research as far back as 1981, research on Cross-device interaction accelerated with Mark Weisers article on Ubiquitous Computing. This was some thirty years ago and the field of Cross-device interaction has become fragmented as the field expanded. As an answer to the fragmented landscape in Cross-device interaction, Brudy et al. recently set out to create a taxonomy to establish common ground for researchers in the field. We use this unification of the Cross-device interaction field, to examine how relevant the state of the art on Cross-device interaction is in the Building Information Context. We do this by designing a set of interfaces for Sweco, a European engineering consultancy company developing a tool for interacting with Building Information Models across devices. In doing so, we carry out Research Through Design. The results show that while the state of art on Cross-device interaction is indeed useful, research on interaction techniques for moving between devices have focused strongly on input modalities and technology which might not be readily available in an enterprise context. Based on these results, we provide a framework that aim at helping future designers make conscious decisions when design for cross-device interaction, as well as a set of consolidated guidelines from the state of art, to help designers create better experiences.

Keywords: Cross-Device Interaction, Design Research, Interaction, BIM, Research Through Design.

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Joachim Pihlgren, Marcus Larsson, Gothenburg, June 2020

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1
Introduction

In academia, movement between devices is labeled as Cross-Device interaction (XDI). With papers tagged as XDI as early as 1981 [62], the field of XDI really took off some thirty years ago with the advent of ubiquitous computing [6]. This research has aimed at leaving the one device one user paradigm that had been prevalent before (and still is in many cases) and find new interaction standards. In the wake of this endeavor, the XDI research landscape has been fragmented. Brudy et al. set out to unify the field of XDI in their Cross-Device Taxonomy [62]. In this taxonomy it becomes evident that a great deal of research has been made on multi-monitor setups and large interactive spaces. Only a fraction of this research has been made on ad-hoc connections with everyday devices such as smartphones and tablets. This is not strange, given the relatively short time these devices have existed compared to the field. But this poses the question of how usable that research is when designing for a modern enterprise context. This becomes a problem of relevance. It is not that research on other configurations of cross-device interaction is less relevant, but rather that the field misses an opportunity to be even more relevant. In collaboration with Sweco, currently developing a tool for interacting with Building Information Models (BIM) intended for use across devices. We take the opportunity to use this unification [62] of the XDI field to see how usable the current state of the art on cross-device interaction is when designing for the BIM context, as a way of either ascertaining or increase the relevance of the field.

Given the question above, we also investigate how we might contribute to the field of XDI, potentially making it even more relevant. By designing cross-device interaction for Sweco, we will conduct Research Through Design (RTD), using the state of the art (SOA) on XDI as guidance in order to both produce guidelines, a framework as well as a set of designs that can promote discussion and inspiration. This will benefit both Sweco as they continue their development and strive towards cross-device interaction as well as the field of XDI as we increase its usefulness in new contexts.

To summarize, this thesis will couple the Building Information Model context with XDI to both promote XDI in a product in development as well as evaluate the field of XDI in this new context. In order to do this we will carry out a literature study to describe the SOA for XDI as well as other relevant fields. This body of knowledge will then support us as we conduct Research Through Design. In order to situate the XDI we are designing for, Sweco has provided us with a part of the tool being developed planned for a later stage, creating and editing geometries in a 3D model of a building, known as meta spaces. Designing for this part will be the design in conducting RTD. When this is done we will discuss the SOA against our RTD findings as well as the system of interfaces realised during the design process.

1.1 The Research Problem

It is unclear how well the current frameworks and guidelines for cross-device interaction stay relevant in the context of BIM, compared to perhaps more common cases such as Facebook or Spotify. Furthermore the advent of new technology might create novel challenges, unconsidered or left out by contemporary frameworks and guidelines. Designing user interfaces while maintaining a coherent user experience can be considered a wicked problem, endeavoring in providing clarity to the relevancy of these frameworks and guidelines brings a problem in itself.
This master thesis will aim to answer the following research question:

1) How usable is the state of the art on Cross-Device Interaction when analysing and designing in a Building Information Modeling context? 2) How can we contribute to the field of Cross-Device Interaction through Research Through Design in this context?

1.2 Expected Results

Expected results include identification of the potential shortcomings in the present body of knowledge on XDI and possible ways to overcome these. In addition to this, the design project itself will produce sketches and wireframes for a system of User Interfaces (UI) for interacting with BIM. The answer to the research question aim to provide value to designers through a dimensions framework and guidelines when designing for XDI, as their toolbox of methods and techniques is extended and refined. There is also the industry, which may see an increase in productivity, or a decrease in resource waste. Finally, designers can access a body of knowledge better tuned to the needs of users.

1.3 Stakeholders

For this thesis, there are some apparent stakeholders. Initially there is us and Chalmers University of Technology. The university has certain guidelines and requirements that needs to be fulfilled in line with the faculty in which it is written to be considered for passing approval. These guidelines will influence how work is carried out in relation to authors and the assigned supervisor, both of which are motivated by academic interests.
Another stakeholder is Sweco, the company and provider of the platform that seek to gain knowledge on the subject. Sweco possess a technical interest in the results produced by this study and expects a low fidelity prototype that their teams can use as a basis for discussion. The users i.e. their staff and clients are also to be considered as stakeholders since they will eventually come to develop and use the product. These may include in-house architects and engineers but also by extension

building maintenance personnel, public employees or other personnel using the end product.
Despite relying on different motivations for the answers to the research question posed, we can see no conflict of interests. Sweco has asked for best practices and guidelines for designing XDI as well as a set of designs that can serve as inspiration. As such it has been in Sweco's interest to promote exploration more than anything else. This lines up well with the academic goals of research through design.
After the design project there is the potential benefitters of the resulting framework intended to help them with their separate product. We see these as designers working in BIM contexts or looking for insights gathered from literature SOA review in combination with a design project, when designing for XDI contexts.

1.4 Background

1.4.1 User Experience and Cross-Device Interaction

Research, frameworks and best practices within the topics of user experience (UX) and UIs originate from a time where interaction in most cases were carried out by a single user on a single device [51, p.338]. This usually involved a desktop computer requiring the user's full attention. In 1988, Donald Norman wrote that a user constructs a mental model of a system [38]. He further states that the user's mental model, of the system, is often different from the designer or developers' mental model and that the goal is to allow the user to develop a mental model consistent with the design model. Designers began to explore the meaning of effectiveness, efficiency, and satisfaction in the specified context of use for their products. At the time, these were most often a single device in a single context. In 2005 the term inter-usability was coined by Denis and Karsenty [12] as a way of describing UX over several devices. A framework and design principles were developed that stressed that when transitioning between devices we need to be able to transfer that knowledge. The knowledge gain on one device may be transferred and used in an interface for another device, as long as the interfaces between devices are similar enough. However keeping interfaces similar may not always be a realistic option [12, p.15]. Although inter-usability systems have changed considerably since then, dimensions such as knowledge- and task continuity, inter-device consistency, transparency and adaptability were adopted as a language for understanding inter-usability. Years later Wäljas et al. [27] defined concepts such as *composition*, *consistency* and *continuity* as the parts of a coherent experience, when interacting with a system on different platforms. Wäljas et al. concludes that these are the factors influencing UX across devices the most. Although the system investigated in the paper can be considered dated, the framework and conclusions are still relevant to this day [51].

1.4.2 Building Information Modeling

Building information modeling (BIM) and the resulting Building information models (BIMs) are representations of the physical and functional attributes of buildings and are "based on technology incorporating information in three dimensions (3D) and integrates the necessary information required by Architecture, Engineering, Construction and Facilities Management" [57, p.1]. BIM aims at providing both construction information inside of the building such as geometric and semantic views and leaves out surrounding information outside of the building such as geographical information and environment. BIM enable an overview over a building's design, the interacting technologies, processes, policies and operations throughout the facility's life cycle [57, p.2]. This allows project stakeholders to share information during a project. BIM can be as simple as 3D CAD models used to represent a facility but can also include detailed information regarding cost, accessibility, safety and data regarding energy. The rise of BIM of have proven to be of great value during building construction while enabling surrounding environment view, something that is outside the scope of this thesis. Other typical uses of BIM as a tool for evaluation and analysis involve energy performance [66] determination of floor spaces for valuation, viability analysis for CCTV placement and facility management for planning of utilities and planning evacuation [48]. Other benefits with the application of BIM include reducing costs and accuracy of cost estimates, better generation of constructions documents and as a tool for visualization of the project [56, p.767]. The shortcomings include personnel not being familiar enough with BIM and realizing the capabilities or not having the knowledge or education to operate these. Hardware upgrades, the cost associated with training and some lack of standards are some of the additional shortcomings [56, p.767]. BIM can be used in different contexts: construction, facility management, asset tracking and predictive maintenance. This thesis will not cover BIM for construction. Instead focus will be on displaying, connecting and interacting with data associated within BIMs.

2

Theory

Brudy et al. [63] provide one, united, starting point for addressing issues of cross-device interaction. In their paper they analyse 510 papers and other literature concerning cross-device interaction and synthesize the field. Their paper will be the backbone of the state of the art as described in this thesis as they provide an ontology of cross-device terminology, a taxonomy of cross-device design space dimensions, and an overview of interaction techniques for different phases of the cross-device interaction. Furthermore, they also provide common application domains and evaluation strategies. These contributions will be detailed further below along with litterature on XDI design and evaluation.

2.1 Cross-Device Interaction

Brudy et al. [63] divide the field of cross-device interaction into areas of trends over time: early work on multi-monitor setups, the advent of multi-display/surface environments and the most recent, ad hoc cross-device use. This thesis will primarily concern itself with the last area, ad hoc. This area is described as "...focuses on mobile and flexible ad hoc cross-device setups. Enabled by ubiquitous availability of smartphones and tablets, this research strives towards individual or collaborative applications spanning across portable devices, providing a digital information space to support the task at hand..." [63, p.3].

In their analysis, Brudy et al. [63] found that many of the terms were used interchangeably within the field. For instance, cross device, multi-device and distributed are used interchangeably as umbrella terms when talking about cross-surface, multi-surface and trans-surface interaction. This could be because earlier work done in the field focused on multi-monitor setups (see Area 1 in [63, p.3].). Later research, however, has focused on ad hoc cross device set ups with smartphones and tablets becoming household items. In this thesis, cross-device will be used where no meaningful semantic difference is inferred. This is motivated by the fact that a majority of the papers cited in the taxonomy labels in favor of cross-device. It should be noted that Brudy et al. does not include multi-user interfaces in their ontology. However, in their taxonomy, they do include multiple users with one device each (1...1 x 1...1) and several users several devices (n...m) in their relationship dimension. They also hint at the possibility of multiple users in the scale dimension, when looking at social and public scales.

2.1.1 The Taxonomy

The taxonomy describes key characteristics, or dimensions, in the field. These are Temporal, where interactions are considered to be simultaneous or synchronous i.e. looking at TV and browsing on a smartphone or tablet at the same time, or asynchronous i.e. browsing an online shop on a laptop and then continuing on a smartphone or tablet. Because of the requirements stated by one of the stakeholders in the project, this thesis will mainly concern itself with asynchronous interaction. *Configuration*, defined as "the actual setup of the cross-device system as well as its use of input and output modalities". Here, asynchronous interaction is divided into two categories, "interfaces that allow migration across devices, and cross-platform research to make applications run consistently across diverse operating systems" [63, p.5]. The *relationship* between people and devices, this relationship is defined as <number of users>...<number of devices>. 1...m, then, refers to one user with m devices where m > 1, this is also called cross-device workstation. 1...1 x 1...1 represents multiple 'one user one device' constellations and n...m represents multiple users with multiple devices where n and m > 1. These are called collaborative settings. The scale dimension relates to the scale of interactions. This scale is shown as the range: near, personal, social, and public rooms and buildings. *Dynamics* concern spaces, where the space for interaction is either fixed, semi-fixed or mobile. The mobile space focus on portable devices which will be the main focus of this thesis, due to the requirements, as stated by one of the stakeholders in the project. The final dimension is *space*. This dimension makes a division between co-located and remote interactions. The bulk of the research they've analysed concerns co-located scenarios. Again, because of the requirements of the project, this thesis will mainly concern itself with remote asynchronous interactions.

2.1.2 Application Domains

Brudy et al. [63] found a range of different applications for cross-device computing in which they identified what they call nine high level application type clusters. Out of these, *knowledge work*, *data exploration*, *mobile computing*, *collaboration* and *software development* are relevant for this thesis. The remaining four are *home computing*, *games and installation*, *education and health*. *Knowledge work* is the most researched application found during their analysis. It typically includes information management across devices, sharing information and resources, multi-device activity and task management or productivity and creativity tasks. Information management and sharing across devices are two probable applications for the project described in this thesis.*Data exploration* is seen as gaining traction as an application domain from year 2000 and onwards. The use of mobile devices for information visualization created a need for a new interaction vocabulary and concepts for these devices.

2.1.3 Interaction techniques

A total of 351 papers from the corpus analysed by Brudy et al. [63] mention interaction techniques. These techniques are called the fundamental methods people use in cross-device computing by the authors. The techniques are divided into three phases of cross-device interaction, 1) **configuration phase**; 2) **the content engagement phase**; and 3) **the disengagement phase**. Further, these interaction techniques are categorized based on their input modalities: **on screen**, **around the device**, device **motion**, **changing the shape** of the devices, and using **body gestures**.

2.1.3.1 The Phases

Brudy et al. describe the **first phase** as being focused on pairing, combining, coupling and other aspects when setting up cross-device configurations for multiple devices. This phase is supposed to support the creation of relationships between devices so that cross-device interaction can occur. The category of interaction techniques with the highest frequency of techniques mentioned in the corpus they analysed is device **motion** in 2D or 3D space. The **second phase** concerns "...direct or indirect interaction with content, data, visualizations, applications or interfaces that are spread across multiple devices". It is unclear to us if one can engage in any of the former mentions, e.g. content, without also interacting with the interface. The most conventional technique in this phase use direct touch or mouse interaction. **Phase three** is the least researched phase, focused on how users stop the cross-device content engagement on a device. Again, the most common category here is device **motion**. The authors point out that interaction techniques might span across two phases i.e. pairing and sending data between devices with one motion.

2.1.4 Evaluation Strategies

In their analysis, Brudy et al. [63] also cluster studies into what they call five evaluation strategies. These are **informative**, **demonstration**, **usage**, **technical**, and **heuristic**-evaluation. **Informative** evaluation aim to provide insights into the needs and problems of users and often precede design work. This is analogue to the empathize phase of many design methods. **Demonstration** display what a cross-device system or interaction technique does and how it is used by users. It does not involve deployment but rather shows how well a proposed solution is applicable to a problem. **Usage** requires deployment and will not be employed with in the scope of this thesis. **Technical** evaluations present in the corpus analysed, intended to show how well a system works. However these papers exclusively evaluated tracking technology, which is out of the scope of this thesis. **Heuristic** evaluation is mentioned only in a handful of papers, likely due to the lack of specialised heuristic metrics for cross-device system usability evaluation. There is also an inherent danger in heuristic evaluation because reliance on simple metrics can produce simplistic progress. As such, **heuristic** evaluation will not be exercised within the scope of this thesis.

2.2 Multiple User Interfaces

Seffah and Javahery [11] define Multiple User Interfaces as interactive systems that provides:

- access to information and services using different computing platforms;

- multiple views of the same information on these different platforms;
- coordination of the services provided to a single user or a group of users;

By computer platform is meant a combination of computer hardware, operating system and user interface toolkit. This means that any MUI must allow for multiple such combinations and must have different views tailored to these combinations for presenting information. At the same time cross-platform consistency and universal usability needs to be kept intact [11]. Furthermore, the services provided must be coordinated to allow both a single user and multiple users. They go on to present characteristics of (a) MUI:

- It allows a user to interact with server-side services and information using different interaction/UI styles.
- It allows an individual or a group to achieve a sequence of interrelated tasks using different devices.
- It presents features and information that behave the same across platforms, even though each platform/device has its specific look-and-feel.
- It feels like a variation of a single interface, for different devices with the same capabilities.

Note that the second characteristic would be labeled as ASYNCHRONOUS interaction by Brudy et al. [63]. These characteristics defines what a (good) MUI does. Seffah and Javahery [11] then go on to provide what they call major intrinsic characteristics of a MUI:

- Abstraction: All information and services should be the same across computing platforms supporting the same level of interactivity, even if not all information and services are shown or needed for all platforms.
- Cross-platform consistency: A MUI can have a different look-and-feel while maintaining the same behaviour over different platforms.
- Uniformity: A MUI should offer support for the same functionality and feedback even if certain features or variations are eliminated on some platforms (Ramsay and Nielsen 2000, as cited in Seffah and Javahery [11]).
- User awareness of trade-off: It would be acceptable to have a simplified version of a program that excludes certain less-important features (such as specifying a seating preference) that are present in the more advanced version. Missing these features is a trade-off that the user would be willing to make in return for the benefits of being able to use the system in mobile contexts.
- Conformity to default UI standards: It is not necessary for all features to be made available on all devices.

2.3 Composition, Continuity and Consistency

Denis and Karsenty further developed the research area of MUIs and defined the previously mentioned factors involved when transitioning between devices and systems [12]. Their work early on defined the characteristics of MUIs and a set of design principles, but it also laid the foundation for frameworks such as the one created by Wäljas et al. [27] in which three services, Facebook, Nokia sports tracker and Dopplr, were studied and analysed. Systems allowing for cross-device interaction were described by Wäljas et al. as *cross-device systems*. The three key components making up this system is described as Composition, Continuity (fluency of content and task migration) and Consistency. The resulting framework i.e. how to best design cross-device systems is broken down into a set of distinct and characteristics that directly affect UX [27].

2.3.1 Composition

Composition is dependent on: 1) Component Role allocation; defines expectations and how users perceive the purpose of each system component. The designer can either limit the functionality on a specific platform or they can provide full functionality on all platforms. Users can either allocate task-based or situation-based roles where the former means that a user uses a specific device for a specific task, and the latter that the user instead have the possibility of completing a specific task using multiple devices. We as designers need to understand the situation in which the user interacts with the different devices making up the cross-device service. 2) Distribution of functionality, this means that the designer have the possibility of, for example, limiting functionality to specific situations and devices. 3) Functional modularity, defined as how each device adapts to different situations, and some functional modularity is suggested even in highly specialized systems. The composition influences what a user expects from the system, and therefore, the system role allocation needs to be in line with how the functionality is distributed.

2.3.2 Continuity

There are three parts that Wäljas et al. suggest makes up continuity: *cross-platform transitions*, *task migration* and *synchronization*. *Cross-platform transitions* means that users need to be able to transition from one device to another and the potential pitfalls is that the user does not have sufficient information to go from one device to another. It is simply not enough that devices are connected to each other. *Task migration* and *Synchronization of actions and content* regards to how well these transitions can be carried out, since users expect to see the same content and states of the system. Best practice is to make sure the system is up to date on all devices so that the user does not need to think of unnecessary switches between devices.

2.3.3 Consistency

There are several parts to consistency: *perceptual consistency*, *semantic consistency* and *syntactic consistency*. To support *perceptual consistency*, it is best practice to design for a similar look and feel across devices. *Semantic consistency* can be accomplished by using a coherent terminology and symbols across devices. Providing a coherent way of navigating on all devices is an example of establishing a consistent mental model of the logic when a user interacts with the system. Lastly, *syntactic consistency* refers to the operations for achieving goals across the systems. If a system of interfaces afford the same functionality and that functionality is achieved by the same operations, there is syntactic consistency.

The intrinsic characteristics outlined above suggested good practices when designing cross-device interaction in relation to its functionality. These definitions are very much inline with that of Cross-Device Interfaces described by Brudy et al. and so these characteristics and good practices can be used as guidelines when designing the interfaces and choosing interaction techniques during the course of the project. It should be noted that the research described has been around for some time. This does not mean that the guidelines can't be used. However, instead of blindly following them and trusting in the assumptions made by Seffah and Javahery [11] and Wäljas et al. [27], we can follow the guidelines and evaluate the results of the effect on our own implementation. Necessary deviations can then be made on grounds of these results.

2.4 Key Components of Cross Device UX

When identifying the key components that make up UX, it becomes a necessity to separate these into the most established and traditionally used metrics for measuring UX. **Efficiency** is referred to as the 'the resources expended in relation to the accuracy and completeness with which users achieve goals' [54, p.38]. It is most commonly measured in *task duration* and *action count* usually meaning time spent on task, and how many clicks or taps that enabled the user to achieve the task. **Effectiveness** is a accompanying metric and is defined and referred to as the degree to which the software allows the user to complete a task with precision and completeness. This is usually measured by looking at *task completion* and *errors*, since those metrics allows designers to get a glimpse of how well the system is capable of letting users carry out tasks [54, p.37-39] [50, p.31]. Majrashi identifies four additional factors influencing UX such as **productivity**, **learnability**, **recognition** and **satisfaction** [54, p.38]. **Productivity** concerns the useful output of the system resulting from user interaction and can be measured both quantitatively and qualitatively. In addition, it can also be measured through the periods of unproductiveness in which the user is forced to perform other tasks not relevant to the goal. **Learnability** is not as usual of a measurement of UX. The definition most relevant to UX evaluation is that learnability states that "the system should be easy to learn by the class of users for whom it is intended" [1]. Majrashi means that this broad definition gets its value to us when separated down into *initial learnability* (measured using efficiency and effectiveness) and *extended learnability* (user performance over time). Last but not least is **satisfaction**, a metric which often includes measuring overall satisfaction directly after a task or via a post test questionnaire. All of the mentioned metrics are relevant when discussion the overall UX of a system, not least when concerned with a system spanning multiple devices. The most commonly used: efficiency, effectiveness and satisfaction will be considered during our evaluations. Satisfaction and learnability are the more complicated metrics to measure. Satisfaction will be measured via a CPUS questionnaire (see Section 2.6) based on the 'system usability scale', a well established form of measuring overall satisfaction [58]. Learnability is ignored by Majrashi due to their respondents only performing tasks once and study's inability to recruit the same participants a second time. Despite this, discussions regarding the learnability and how to consolidate it are discussed. According to the findings, consolidating learnability is usually supported by designing for consistency. The reason being that it would allow users to only have to learn one interface in order to perform well in the other interfaces [54, p.95]. Here we can identify an overlap between research by Wäljas et al. and Majrashi. Majrashi states that appropriate application of principles when designing for consistency, could prove beneficial for the learnability, transparency and recognition of a service. By transparency, Majrashi refers to the extent the design of each UI is clear enough for users to understand the available functions for each device [54, p.124]. Recognition is defined by Majrashi as the extent to which the system enables users to recognize elements rather than forcing them to remember information [54, p.124]. Tending to the proper design of consistency, designing visual appearance that maintain elements and their placement over platforms would allow the user to conform visual and spatial memory as an important aspect of consolidating for learnability [54, p.105]. In our study, the aspect of learnability will also be assessed via an STS questionnaire (see Section 2.6). Since we won't aim at recruiting the same participants over time, just as in Majrashi's, we will only try to measure initial and not extended learnability.

2.5 Meta Spaces

This project will concern itself with one of the tools to be developed for a BIM platform. Because BIMs are often implemented as 3D models, they are iconic representations of what they signify. The information tied to these models are also often related directly to the properties of the building (although not necessarily). The stakeholder of this project wants to allow users to create arbitrary collections of such rooms and spaces, in what we call meta spaces, and tie arbitrary information to them such as rental cost, number of chairs, network ports and so on to that collection. Each item in this collection (meta space) is signified by a specific 'space' or a room's relative position and volume, i.e. its position and extension in the 3D-model. The smallest meta space is a collection of one room or 'space', i.e. a room can constitute its own meta-space as well. But because meta spaces are collections, they don't require these spaces to have relative positions next to each other. A meta space can be a collection of all rooms that belong to a certain office. Furthermore, a meta space can be a collection of meta spaces, providing the possibility of several dimensions of meta spaces. When we say that these collections are arbitrary, it is with a caveat. The possible configurations will be limited in the system to certain dimensionalities and categories. It is perhaps likely that the information tied to these meta spaces will also be limited, but allowing for arbitrary information doesn't pose as complex a challenge as allowing for infinite dimensionality in meta-space collections. This is not to say that the medium for the information will not be limited to specific kinds. Back, then, to the tool to be created. It is the stakeholders intent to create a tool that allow users to create and manipulate meta spaces and their information. It is upon us to design the system of interfaces that allow this interaction, across devices.

2.5.1 Virtuality and Virtual Spaces

Nate Combs [9] delves into the semantics of Virtual Worlds in an attempt to calibrate how it is used without creating a too narrow definition. He takes off using Richard Bartle's 2003 (as cited in [9]) definition of world: "In this context, a world is an environment that its inhabitants regard as being self-contained. It doesn't have to mean an entire planet: It is used in the same sense as "the Roman world" or "the world of high finance". Combs then go on to semantically analyse virtual. He starts by defining Real as "That which is" and Imaginary as "That which isn't". He then defines virtual as "That which isn't, having the form of that which is". Finally he synthesizes this into "Virtual Worlds are places where the imaginary meets the real". This definition is a bit problematic. He uses a definition of world that seems to depend on there being "inhabitants" for there to be a world. As is hinted at, worlds are often synonymous with planets. But planets doesn't seem to be subject to the same criteria of inhabitants. Mars then would be a planet but not a world (yet, if we're to believe Elon Musk). But it still is a, real, place in physical space. So perhaps then, place is a better word for any environment that doesn't depend on inhabitants. So why does Combs say that virtual worlds are places, without binding those places to a subset where inhabitants are a requirement? The definition would have made more sense if it were "Virtual worlds are worlds where the imaginary meets the real" as this would have kept this bond.

The definition of virtual is interesting however. "That which isn't, having the form of that which is" seem to imply that the imaginary thing must have the form of something real. It is unclear if this is true, can I not conjure up something that has never existed, in my mind? There are probably supporters of both views. Another interpretation would be that, that which isn't, is represented in the form of something that is, i.e. a model of the imaginary thing. But wouldn't the thing also be real at this point? A third interpretation is, that which isn't (real) represents something that does exist. This would be inline with a digital representation of say a building in real, physical, space. Why not a 3D model of a building? This would make that 3D model virtual by definition of "that which isn't, having the form of that which is". A virtual place then would be a point in a space where any virtual thing is, and the space where it exists would constitute a virtual space. This is all but too philosophical but it allows us to place our meta spaces as a subset of virtual spaces, by virtue of meta spaces being representations without physical extension, that represents something that does in fact exist.

2.5.2 Interacting with Spaces

In the book Making Sense of Space [44], Kuksa et al. seek to establish common ground, make sense of digital reality as well as agreeing on design principles and rationales in relation to virtual spaces (AR and VR). The authors speculate that these new platforms will change or enhance the way that we consume media and communicate with each other. In the near future, there will be a rise of a new, more semantic, web which enables more extensive automation made possible by the promises of 3D web browsers [44, p.29]. The designer that seek to design within this future realm, called *participant-digital-space interaction*, must possess relevant

knowledge of the involved design principles when accommodating for existing demands and when communicating the intended design experience to the user. The selected design principles are adopted from the Center for Universal Design at North Carolina State University [4]. Kuksa et al. have chosen these as the most relevant principles when designing for digital spaces. These become particularly important when the designer may rely on numerous devices for interpreting user activities [44, p.30].
The design principles as listed in [44, p.29-30]:

- Equitable use – this means that design should be useful and marketable to people with diverse abilities.
- Flexibility in use – this implies that design should accommodate a wide range of individual preferences and abilities.
- Simple and intuitive use – this suggests that design should be easy to understand, regardless of the user's experience, knowledge, language skills or current concentration level.
- Perceptible information – this means that design should communicate necessary information effectively to the users, regardless of ambient conditions or the user's sensory abilities.
- Error tolerance – this suggests that design should minimize hazards and the adverse consequences of accidental or unintended actions.

The above listed design principles serve to guide the designer regardless form or device the digital space may take or be placed in, be it on screens, projectors, theatres or in head mounted displays. Because of their universal framing these guidelines can aid us as we design for interaction with virtual space whilst maintaining focus on accessibility.

2.5.3 Collaboration and Immersion in Spaces

On the topic of digital collaboration research, Heldal et al. showed that the degree of immersiveness in combination with device symmetry affected task performance. In five experiment settings with 220 participants, the results of the study showed that collaboration performance depended on symmetry between devices, where task performance increased the more immersive the device used for interaction were as well as if both peers participated on the same type of device [13]. The experiment involved manipulation and repositioning of 3D objects for task completion which relates to the type of 3D manipulation framed in the research question. The results of the study indicates that immersion plays an important role in object focused problem solving tasks in which the user can manipulate objects in a digital environment. For the time, state of the art immersive projection technology systems (IPTs) were used and compared to a physically collocated environment which had the highest degree of completion and the best performance. The symmetrical IPT setting performed second best and symmetrical desktop setting had the lowest degree of completion performance. This becomes interesting given the framing of this thesis since distributed collaboration is probable to happen in an ASYNCHRONOUS manner [63]. Heldal and Widestrom [13, p.7] then, urges us to think of what information to present at a given time and a given device to keep devices and information as symmetrical as possible. If workers are to work on the same problem task on separate devices, we as interaction designers need to consider what information and what framing to use since immersion into the system affects copresence and manipulation ease. If this is not possible, Heldal et al. recommends keeping settings as symmetrical as possible [13, p.7].

2.6 CPUS and STS

One of the more acknowledged methods of evaluating single device usability is the system usability scale (SUS) [58]. This is something that has been confirmed when evaluating ten year of usability evaluation using SUS [19] However this does not help our case since this scale is, as mentioned, designed to evaluate a single device or UI and its usability. Combining the SUS and the work by Denis and Karsenity [12] has been performed and evaluated by Majrashi [54, p.36-39] with the goal of giving XDI a quantifiable score. It was given the name cross-platform usability scale (CPUS) and includes eight positive and negative questionnaire statements in randomized order. A likert scale 1-5 ranging from "Strongly Disagree" to "Strongly Agree" was used as a post test questionnaire. The eight questions of CPUS:

1. I felt productive when using many platforms (positive statement)
2. It was easy to use each user interface (positive statement)
3. I found that each user interface across platforms was designed the way I expected it (positive statement)
4. I felt that the cross-platform user interface needed much improvement (negative statement)
5. I found the various cross-platform functions to be well integrated (positive statement)
6. I needed to learn how to use each user interface separately (negative statement)
7. I noticed inconsistencies between cross-platform user interfaces (negative statement)
8. I was frustrated by the different designs of each user interface (negative statement)

Seamless transition between devices can be described as a way of letting users retrieve knowledge gained from one interface and adapt it to a new device and context [12] where knowledge is the users' representation of the system. Denis and Karsenty state that "users must believe that the multi-device system shares their own memory of the data state" [12, p.6]. When this is achieved, the user can utilize the shared context and won't feel the need for repeating actions on different devices. Given the research of Denis and Karsenty, Majrashi [54] suggest three additional questions, investigating seamless transition between devices. This seamless transition scale (STS) focuses on the continuity aspect of interaction whereas the CPUS focuses on user satisfaction and UX.
The three questions of the STS questionnaire:

1. I am satisfied with the amount of time it took to resume the interpreted task from [device A]

2. I found I needed to remember information from the user interface on [device A] to be able to continue the horizontal task using the interface on [device B]
3. I felt I could continue seamlessly in my horizontal task after switching from the user interface on [device A] to the user interface on [device B]

2.7 Interpreting SUS (and CPUS)

The SUS scores range from 0 to a 100 and Sauro [60] propose five ways in which these can be interpreted. These are Grade, Percentile Range, Adjective, Acceptable and Net Promoter Score. Here we take a closer look at three of them: Grade, Adjective and Acceptable. Grade is closely related to Percentile Range and follows the scale common in schools: A-F. Sauro [60] put the grades on a curve to match the distribution of grades with the normal curve. He then plot the SUS score against these grades on a 12 point Likert scale from A+ to F. The grade of B+ would then correspond to a score range between 77.2 and 78.8. This is a common way of comparing scores relative to each other [19].

The selection of Sauro's [60] SUS Interpretations			
Grade	**Adjective [19], [22]**	**Acceptable [19], [22]**	**Score**
A+	Best Imaginable	Acceptable	84.1 - 100
A	Excellent	Acceptable	80.8 - 84.0
A-		Acceptable	78.9 - 80.7
B+		Acceptable	77.2 - 78.8
B		Acceptable	74.1 - 77.1
B-		Acceptable	72.6 - 74.0
C+	Good	Acceptable	71.1 - 72.5
C		Marginal	65.0 - 71.0
C-		Marginal	62.7 - 64.9
D	OK	Marginal	51.7 - 62.6
F	Poor	Not Acceptable	25.1 - 51.6
F	Worst Imaginable	Not Acceptable	0 - 25

Table 2.1: The three suggested interpretations from Sauro [60] and the SUS score ranges.

The last two ways we are looking at from those proposed by Sauro [60] are Adjective and Acceptable, created by Bangor et al. in [19]. Acceptable tries to answer the question "...what constitutes an acceptable SUS score.". Bangor et. al [19] suggest that a score lower than 50 is unacceptable whereas a score of above 70 is acceptable. Bangor then continues by stating that scores in between 50 and 70 should be considered marginal and subjects for ”increased scrutiny and continued improvement”. Finally, Adjective is a way of relating a SUS score with a word rather than a grade. Adjective represent SUS scores on a seven point scale produced by Bangor et al. [19], [22] as a list of words: Worst Imaginable, Awful, Poor, OK, Good, Excellent and Best imaginable; ranging from lowest to highest. The process for producing

these is discussed in detail in Bangor et al. [19], [22], however the Awful adjective didn't produce significant results in testing and as such Sauro [60] does not include this adjective in his proposition. Adjective aims at covering a flaw in using grades to represent scores, it is not a validated concept in terms of SUS , despite its usefulness when talking about scores in a relative manner (i.e. comparing scores) [19].
As described in the section above (2.6), CPUS [54] is a derivative of the SUS questionnaire aimed at measuring Cross Platform Usability. However, the CPUS max score is 80 which does not readily map to the ways of interpreting above. To solve this we multiply the CPUS scores from our planned evaluation with a factor of 1.25. This will make our results map onto the interpretation scales.
These three ways then, will be used to interpret the scores from the planned CPUS questionnaire later on in this study, in conjunction with the scores themselves to help us understand the usability of our design, as suggested in [22].

2.8 The possible pitfalls of Usability Evaluation

Greenberg and Buxton [21] writes their paper as a response to an increasingly biased view on the importance of quantitative usability evaluation in HCI journals such as ACM. According to them, it has come to the point where papers are critiqued solely on the omission of such evaluations and where researchers choose research questions that allow for quantitative usability evaluations to increase their chances of being published. While the benefits are great, Greenberg and Buxton[21] bring to light several ways in which usability evaluation can do more harm than good. Two of those ways are detailed below.
Using usability evaluation too early in the process, e.g. at the sketching stage, can lead to local hill climbing. Instead of exploring other possible designs, focus is aimed at optimizing the current design. This might make designers miss designs with a greater maxima.
Using usability evaluation to test an hypothesis can seem like good science. The hypothesis then, is often defined in terms along "When performing a series of tasks, the use of the new technique leads to increased human performance when compared to the old technique". However it is easy to unknowingly create favorable test conditions for the specific design. This is because the test is used to validate that the current design is worth pursuing, in other words: usability testing is used as 'existence proof'. But a good usability score for that test case is a weak indicator of how well it performs against other techniques (other than in that specific case) [21, p.3].
In the course of this thesis, we will use usability evaluation as one method to test our designs. We will also use those results in our discussion regarding how well the current body of knowledge relates to our case. Because these pitfalls have been made explicit, we can also address them in that manner. Usability testing will not be conducted to evaluate the appropriateness of different designs. Furthermore, this thesis does not aim to claim that any one design or interaction technique is better than any other. Instead the aim is to try and see how well these relate to our use case.

3
Methodology

In this section, we detail the methods we will use as well as two other methods, and their respective strengths and weaknesses.

3.1 Research Through Design

Research through design, while not as widely known as more common methods such as observation, is not as new as one might think. Frayling mentions research through art and design as early as 1993 [2, p.5]. According to Frayling, it is a method used for degree projects at colleges, though less frequently used than research into art and design. He describes three use cases: *materials research*, i.e. researching existing properties or way to induce new properties in to materials. *Development work*, manipulating existing technology in novel ways, producing previously unseen results. *Action research*, keeping a research diary, recording the step by by step execution of a practical experiment.

That there is value in this method for use in an interaction design context is indicated by more recent discussion on how to formalize and apply the method in human-computer interaction (HCI). Zimmerman, Forlizzi and Evenson [18] highlight the lack of integration between design research and design practice in the HCI community. They state that by conducting research through design, designers can "...produce novel integrations of HCI research in an attempt to make the *right* thing: a product that transforms the world from its current state to a preferred state." [18, p.493]. In order to formalize this, they suggest four lenses for evaluating research contributions. These are *Process*, *Invention*, *Relevance*, and *Extensibility*. *Process* regards detailing the processes with which design was carried out, so that the process can be reproduced by others. However, as customary in other fields of research, the results needn't necessarily be reproduced. The contribution from using the method must produce a significant *invention*. The researchers must show that they've come up with a "...novel integration of subject matters..." [18, p.499]. To prove the novelness, a rigorous literature review must be carried out. Furthermore, the researchers must display how progress in technology can significantly advance the field. *Relevance* becomes the mark of validity, compared to other fields of research where reproducing results is key for establishing validity. This means that the burden lies on the researcher to map out the current state and the preferred state, and motivate why that state is the preferred one. The researcher must also communicate the attempts made at reaching this preferred state. If the preferred state is not properly motivated, the method becomes self-indulgent. The final cri-

teria, *Extensibility*, means that the outcome from the method, the results, should, in itself, be usable in future research through design endeavours i.e. the research should be documented in a way that makes explicit for the community how this new knowledge can be used in the future.
Gavner [32] details and confronts critique aimed at either destabilizing the position of Research Through Design as a scientific research method, or arguing for a more unified and formal way of conducting the method. One of these critiques is also a stab at Zimmerman, Forlizzi and Evensons [18] *Process and Relevance* criteria for evaluating research contributions. As they state, despite reproducing the process described in a project using research through design, the results will not necessarily be reproduced as well. As Gavner [32] states, this is in contradiction with Popper's (1963, as cited in [32]) criterion of falsifiability, if a theory born out of research through design works some of the time, and some of the time not, it is not falsifiable. Gavner does not contend this, instead he proposes that it is not the theory that is the main result from research through design, but the artifacts that result from it. The theories that derive from these artifacts are more like annotations, "...serving to explain and point to features of 'ultimate particulars...'" [32, p.944]. What is meant by this is that each design is a point in a design space. Any theory describing that design, bounds the space surrounding that point, allowing other designers to explore that space and find new possibilities for novel designs i.e. theories in research through design do not specify the way to create good designs, but help us explore a vast, possibly infinite space, systematically, with meaningful starting points.

3.2 Case study

Breslin and Buchanan [20] state that Case studies are tools that can be used effectively for research focusing on the transition between theory and practice, in design too. Despite this, case studies aren't widely used as part of research development in design. According to the authors, there are a few reasons for this. The first one is a lack of objectivity and discipline in reporting design processes, amounting instead to something more akin to self-promotional articles. Another reason is the disbelief in the existence of valuable knowledge from these stories. Instead attributing the success of a design case to the genius of the designer, something that cannot be accessed by means of case studies. Lastly, the case studies that have been previously performed by designers have had the wrong form. They've been written and carried out through a business lens, rather than as a formal research method. Despite this, case studies have been on the rise with in design, at least with in HCI and Interaction design. This is motivated by collections of methods such as [34], where conducting Case Studies is one of the suggested ways to carry out research. Breslin and Buchanan[20] cites four types of Case Studies that are commonly carried out. *Exploratory*, *critical instance*, *program effects*, and *narrative-case studies*. These are not the only one [65] presents illustrative, exploratory, critical instance, program implementation, program effects, prospective, cumulative, narrative, medical, and embedded. According to them, the following are the most common: *Illustrative*: These are case studies aiming at being descriptive. Usually looks at one or two instances and acts as an introduction to a topic. *Cumulative* case studies looks at

many cases of a situation to be able to draw broad conclusions. *Narrative*, presents the findings as a story being told. Finally, *Critical Instance* studies one or more case to criticize common assumptions. Often used to evaluate cause and effect.
At one point, we considered viewing the project done for the stakeholder as a case for a case study. We reasoned that by analyzing and understanding the project from an "outside" perspective, an objective evaluation could be carried out on how well the current state of the art relates to our case. However none of the variants described in the literature we have reviewed really matched our goal. There is also the fact that most case studies are carried out after the fact, not during as would have been the case here.

3.3 Secondary Data Analysis

Secondary Data Analysis or simply Secondary research, is the act of using previous research to facilitate new analysis [34]. It is much like a literature study, but with the primary goal being to analyse existing data, instead of aiding in producing new data, also known as primary research. While there are potential pitfalls in using secondary research such as a lack of control over the execution of the method to gather the data. It might be the case that the wrong questions were asked (in relation to the current research objective) or that the primary researcher unwittingly introduced bias to the process, or simply failed to document properly. On the other hand, secondary data is quick, cheap and can provide many different origins of data for the analysis [67]. We entertained the possibility of using our literature study as secondary data and analysing it as a way of answering the research question. But since we also do produce primary data, this kind of analysis seemed less relevant.

3.4 Journaling

Journaling will be used as a means of collecting data for the research through design, both in order to be able to fulfill the *Process* criteria but also as a body of knowledge to use in the evaluation against the research question. There is no 'do all' technique for properly documenting the process of Research Through Design. This is made evident in Bardzell et al. [52]. They set out to provide a framework for planning and evaluating Research Through Design documentation, but fall short. They do however provide three concerns: The medium of documentation, performativity of documentation and providing equal support for both research and design. These can influence the way the journal is used and what results the journal provide. In their paper they analysed two cases of documenting, one using word and one using a tool developed specifically for documenting research through design, the Process Reflection Tool (PRT) [31]. In Dalsgaard and Halskov [31], PRT is presented as a web application which helps designers document their process collaboratively. This tool is not readily available, but they do outline the components, structures and affordances of the tool. PRT is based on **events**, **subevents** and **notes** being organized in a temporal manner, in their instance a horizontal timeline is used to plot events. Events are discrete activities with a specific purpose, beginning and

end. They do not last longer than a day, if the same activity is spread across many days, each day is one event. **Events** have *titles* e.g. ‘Design workshop’, they have a *timestamp*, *information* i.e. *location*, *participants* and other relevant facts. They have a *conclusion* that sums up the event in terms of insights and decisions for future work. A *description* that details what happened during the event. In PRT images, video and documents can be uploaded to a specific event *(media files)*. If an event is complex, **sub-events** can be added to an event to help provide an overview. Examples of a sub-event would be a single design experiment in a design workshop with many such activities. Sub-events also have titles and descriptions and can have the above mentioned media files attached. Notes are a way to document any non event part of the process such as conversations, e-mail messages or other unscheduled or informal parts of the process. Notes have timestamps, *text-fields* e.g. some way to record plain text and can have media files attached. PRT also provides a timeline view that shows all events on a timeline from which users can navigate to or get more information regarding and event, subevent or note.
Despite not having access to the PRT tool, we propose that the functionality of PRT can be achieved by applying the object structure of PRT to Google Docs. The document disposition can act as a timeline and headings can be used to denote events, sub-events and notes. These headings can then contain the appropriate “variables” e.g. title, timestamp and so on. Because the google echology supports images, links to google photos can be inserted into documents, providing the means of inserting images and videos under a heading.

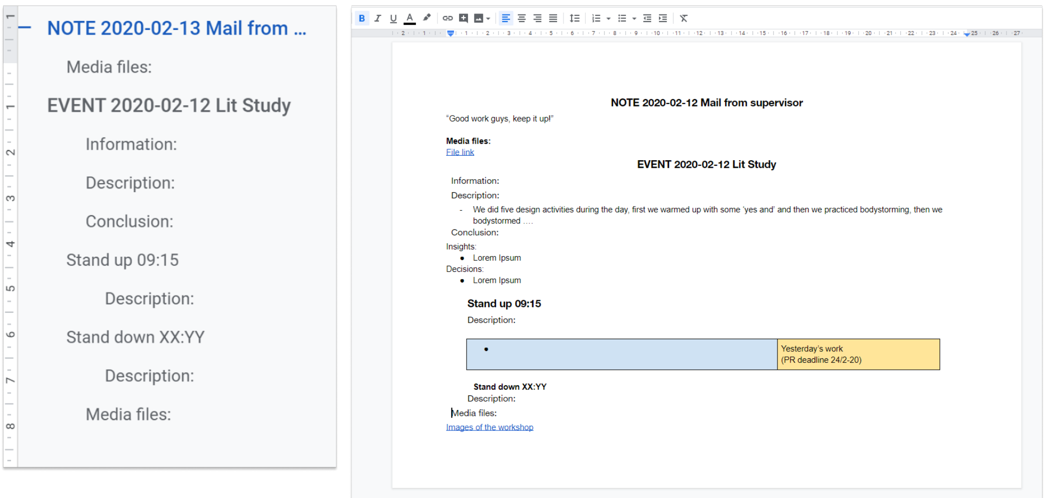

Figure 3.1: This acts as a proof of concept, showing that the functionality of the PRT tool can be achieved, at least mostly, in google docs.

3.5 Design Process

Choosing a design process for this project is a bicephalous matter. On one hand, the right process will guide us towards the best possible design we can come up with, increasing the value to the stakeholders in the project. On the other hand, since we are conducting Research Through Design, the process we choose will directly affect the activities we perform and by extension, how the method is carried out. There doesn't necessarily need to be any conflict between these two goals, but it's worth investigating further.

The research problem is that we don't know how well the current research on XDI relate to the tool we are designing for the stakeholder. The research question, how well does the field relate to our project and how can we use that knowledge to create value, seem to imply that we explore as many possible designs as we can. This endeavor can never come anywhere near exhaustive since there are too many variables, if not an infinite amount. Perhaps then it is better to talk about breadth. If we explore many different kinds of designs, we will have anchor points in design space which either work, or not. This can benefit the project goal as well. By exploring a broad range of designs, we reduce the chances of finding a local maxima. This also aligns with the stakeholder need, they want to have suggested designs for interacting with meta spaces, so that they can use these as a starting point when they reach that state in their development process. It is reasonable then, that our design process should focus more on surveying the design space and make touchdowns into that space. In any case these designs will need to be sprung out of user needs and evaluated against these needs too, so the process must still be user centered. These needs will not change with the designs. If there is a need to be able to space out fire extinguishers in the meta space, the design must always meet this need i.e. functionally, the designs will be the same. It is *how* they accomplish these functions that will vary. Among other, the how is dependent on what interaction techniques are used. Because the designs will still need to be evaluated, the results can be put against each other and provide a relative measure of which design works better than any other.

If we accept the above reasoning, there are a few demands we can make on the design process we need. It still needs to identify the needs of users, it needs to reflect that more than one design will be worked on. It will need to reflect that designs will be taken to an appropriate level of fidelity, such that evaluations can be conducted on the designs. Finally, it needs to reflect that designs will be compared to one another to create a relative measure of performance (measured as user experience and usability).

Figure 3.2 is a modified model of Dam and Siang's [71] five stages of the Design Thinking Process. The first three steps aren't ostentatious. According to Dam and Siang, *Empathise* gains insight into users and theirs needs, by means of consulting experts, interviewing users and so on. This information is then analysed and synthesized into insight, used to *define* the problem statement as a third person wish or need "facility managers need to be able to quickly add information about a space on the fly". Finally, given the insight and the problem statement, ways of solving this problem is explored by means of *ideation* and ideation techniques. In the end, possible solutions are evaluated and a subset of these are selected. We use subset to indicate that our model allows for more than one design to carry on to the *prototyping* stage. This is where our model differs from Dam and Siang. The notion of multiple designs being explored isn't a novel conception however, Parallel Prototyping [34] is a formal method of exploring multiple designs. Hanington and

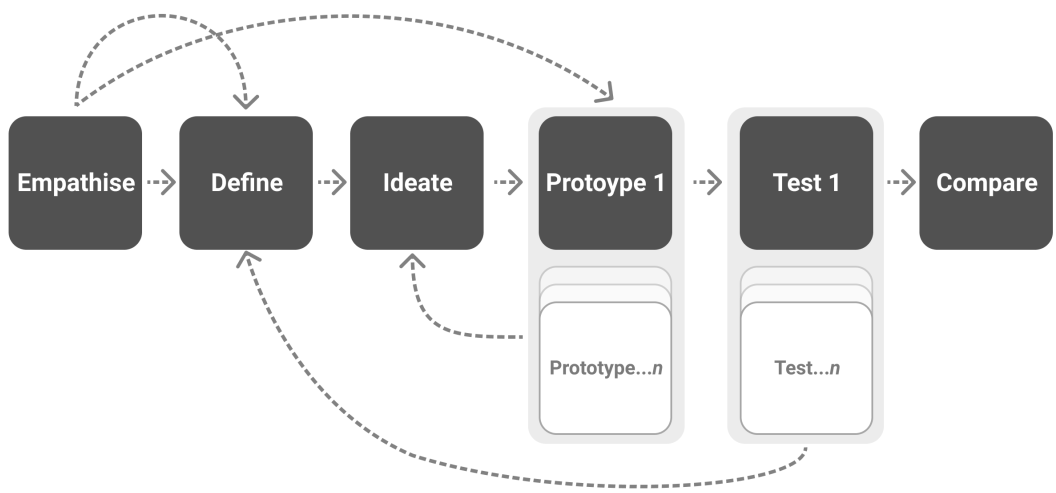

Figure 3.2: Our suggested design process, inspired by Dam and Siang [71].

Martin categorise it as being both generative and evaluative, meaning that it both explores a design as well as evaluates its suitability. Traditionally, however, the method is used before iteration, to help consider multiple designs before selecting the one design to continue with. The advantages to this is that it can help avoid "hill climbing". Despite generally being used to select one design, there is no reason that the benefits from exploring multiple designs wouldn't carry on to later in our model too. That this method exists then motivates our model, seeing as we use it as a means to avoid getting stuck in a local maxima. Our model then goes on to evaluate each prototype, as a means of both iterating and producing a comparable result for the final phase, *compare*. This comparison allows us to pick the design with the highest usability and the greatest user experience to propose to the stakeholder.

4
Planning

4.1 Planned Execution of Design Process

The planned design process						
Phase	Methods					
Empathize	Literature Study	Interviews				
Define	Content Analysis	Affinity Diagramming	Find themes	How Might We?	Feature list	Kano analysis
Ideate	Brain-storming	Sketching				
	Body-storming					
Prototype	Wireframe					
Evaluate	Usability testing					
	CPUS					
	STS					

Table 4.1: A table consisting of suggested methods for use throughout the Design Process.

With the selected Design Process in mind we will detail the intended methods that will serve as the implementation of said Design Process. The project was preceded by a literature study, detailed in the background and theory section of this thesis. This is a necessary step both in science and design, perhaps even more so when the two are combined. With this in the back, we aimed at carrying out interviews to further empathize and understand the stakeholders in project. The data from these interviews will be analysed by means of content analysis using inductive qualitative content analysis using holistic coding [23], [34, p.40].
As a way to extract concrete insights from these codes resulting from the content analysis we will conduct affinity diagramming. There are several reasons for this. The first is to find problems and underlying motivations for these which we can use to create so called How Might We questions [73]. These are questions aimed at allowing designers to ideate around how specific problems might be solved. Second, if we can

identify different kinds of users and their needs we can create user stories. Lastly, we want to understand the tool sufficiently enough to produce a list of intended features for which we can conduct Kano Analysis [34, p.106] on in order to identify a minimal viable product (MVP).
By know we should have sufficient insights and knowledge to begin ideating possible designs by means of brain- and bodystorming, potentially with stakeholders. Then, in order to facilitate the prototyping phase, a series of quick sketches will be produced to lay the foundation for the wireframes which we will evaluate in the last stage of our Design Process. This evaluation will necessarily involve the Cross-Platform Usability Scale and the Seamless Transition Scale as they relate strongly to our research question about how usable the SOA on XDI is when designing in a BIM context. To supplement these we will also conduct Usability Testing using concurrent think aloud (CTA) [34, p.180].

5
The Design Process

In this section we will detail how each step of the design process outlined above was implemented in terms of methods, frameworks and other tools. We will also provide motivations for the methods used, critique against those methods and present alternative methods and the reasons for not carrying those out instead. This detailing of the design process will follow the order presented in Figure 3.2.

5.1 Empathise

The world of building engineering and architecture is highly specialized. With that comes highly specialized tools like BIM and BIM-Viewers such as Dalux and more potent tools such as Solibri Office. As Interaction Designers entering this world for the first time, we felt it important that we get to know both those who work at the company who are building the product as well as potential end users.
However, it is not likely that the intended end user (among Sweco clients) already use the existing tools for creating spaces because this is a task that is commonly placed with BIM-coordinators and architects at Sweco. The tool being developed aims at moving some of the tasks from Sweco personnel out to the clients. The reason for moving the tasks is a perceived need in clients from the view of Sweco. This means that interviewing the intended users might not yield the answers we are looking for, because they are not currently solving tasks that are dependant on the tools. Asking questions about how those tasks are solved today or trying to find pain points in the execution of those tasks would be a moot point.
There is another factor, affecting the availability of potential end users for empathizing. Because information regarding the product being developed can be of a sensitive nature, participants who are not bound by an NDA cannot be made privy to information needed to be able to conduct some of the empathize methods planned. By this reasoning, we decided to conduct interviews with Sweco personnel only.
For this, we conducted semi-structured interviews. These allow interviewers to ask targeted questions while allowing respondents to answer in an open manner. Semi-structured interviews also enables the interviewer to ask follow up questions to clear up any ambiguous answers or get the respondent to elaborate their answer. The objectives of the interviews were to 1) define why the product being developed was needed; 2) why and how similar tools are used; and 3) what the goals for using these tools are. A total of four interviews were conducted (N=4) with interview times ranging from 26 to 46 minutes (M=34 minutes). All interviews except the first was recorded on audio. Prior to the interviews, all respondents were informed about

why the interviews were conducted, what the data would be used for and that their answers would be handled anonymously. For those interviews that were recorded, additional information about the purpose of recording, data handling according to The General Data Protection Regulation (GDPR), and the possibility to withdraw consent were provided prior to asking for consent to record. This information is detailed further in Appendix A. The respondents were recruited from a convenience sample and no compensation was offered for participation. It should be noted that all respondents were employed by Sweco Position AB at the time of the interviews. Each interview was conducted with one respondent, one moderator and one observer. The moderator was tasked with asking the questions while the observer took notes.

The following interview questions were asked:

- Sex, age Who are you, describe your role? Describe what you do?
  - What would you say is your primary task?
  - Describe a regular day?
  - Which (digital) tools do you use most?
- Do you work in any way with BIM?
  - (If yes)
  - How do you use BIM?
  - What do you think works best with BIM?
  - What do you think works poorly or is frustrating with BIM?
  - How would you like that tool to operate?
- What devices do you use in your line of work? (Mobile phone, tablet, desktop computer, laptop)
  - Do you often switch between devices, is that possible?
  - (If yes)
  - Do your devices complement each other?
  - Which device limits you the most?
  - (If no)
  - Why not? What keeps your from switching devices?
  - Do you think there are things your mobile phone can do which other devices can't?
  - What would make you switch devices (even) more often?
- Do you often collaborate or cooperate with others?
  - (If yes)
  - How many at a time?
  - Do you use the same kind of units? ((Mobile phone, tablet, desktop computer, laptop)
  - How do you go about collaborating/cooperating?
  - Why is collaboration needed?
  - What happens without that collaboration?
  - (If no)
  - Why not?
  - Not at all?
  - Across devices?

    - What would be required in order to collaborate?
- Given a tool that lets you work with spaces:
    - What would you expect to be able to do?
    - What would your goals be by using spaces?
    - What need would spaces meet?
    - If a spaces tools existed today, how would you use it?
    - What functions would you like to find in such a tool?
    - What would happen if you could not create spaces?
- There can exist some tension between architects and engineers because they may have different perspectives on the same process. Are there similar tensions in your field of work?

Before settling on interviews, we explored several other research methods for the empathize phase. As made evident from the objectives of the interviews, we mainly wanted to gather qualitative data that was in a way both *summative*, in that we wanted to understand the current state as well as *formative* in that we wanted to extract insights that could inspire the design to come. This left us with two main categories of research methods for the empathize phase besides interviews: surveys and observation. Regarding surveys, while they do allow for a semi-structured format with open-ended questions and free form text fields, interviews are inherently better at mediating the same "dialogue" style data gathering. Surveys also rarely afford the depth required in answers to meet our objectives. This is mainly due to the fact that unless the survey facilitators are present as the respondent completes the survey, if there is any ambiguity to the questions, confusion cannot be cleared up. At the same time, surveys do not allow for spontaneous follow up questions to the answers provided by the respondent. Without the facilitator present, there is also a loss of control in what answers are recorded and thus there is an increase in risk of ending up with poor data e.g. due to respondent fatigue. While these shortcomings can be overcome with a facilitator present, this presence can in itself affect the answers and introduce bias in the results [26].
As it pertains to Observation, a number of techniques were taken under consideration: Fly-on-the-wall [34, p.90], Shadowing [34, p.158] and participant observation [34, p.124]. In our case, fly-on-the-wall runs the risk of producing results that are too descriptive to suit our objectives. Because the observer does not interfere with the subject, it may be hard to get an understanding of the motivations underlying the answers. Shadowing did not seem viable as it requires us to follow the subject around for an extended period of time, also not guaranteeing that relevant topics will be brought up. Many of the interviewers also attend meetings with stakeholders outside of Sweco. Obtaining permission to attend these meetings could prove to be a time-consuming endeavour in and of itself, the alternative being huge blank spots in the observations made during shadowing. All in all, shadowing has a too great a cost to conduct when put against interviewing. Lastly then, there is participant observation. This method lines up well with the objectives, allowing researchers to document behaviors and motivations [34, p.124]. It also provides the possibility of "true empathy" in that the researchers as participants experience the events alongside the subjects [34, p.124]. However, the method is time consuming and even if

full participation is not necessary, it is unlikely that we have the skills necessary to carry out the work of those selected for the interviews.
Collectively, Fly-on-the-wall observation, Shadowing and Participant observation also do not ensure that the collected data relates as strongly to our objective as interviews does. This is especially true in our case where the tool being developed aims at solving BIM related tasks in a novel way. By observing users of existing tools, it is not certain that observations relevant to the new tool will be made.

5.2 Define

After the interviews, the observer notes were complemented by transcribing the audio recordings for all interviews except the first for which there was no recording. As the purpose of transcribing was to fill in any blanks or mistakes in the notes, it was conducted on a sentence level without any framework guiding it. Instead corrections were made to the notes where e.g. the observer had misunderstood a statement or paraphrased such that the note no longer represented the original statement. There are also statements that were not represented in the observer notes at all that were added to the notes. This was done on a subjective basis with the interview objectives guiding the selection process.
In order to gain insights from the interviews, inductive qualitative content analysis using holistic coding was used [34, p.40] [23]. Initially each researcher subjectively coded every data point with one or a few words that captured the essence of that data point. After this the codes were gone through in collaboration. Similar codes were merged into one and codes that were too general were either split into several codes or changed to be more specific. After this, all data points were re-coded based on the established codes, allowing for more than one code per data point.
Categories were then extracted from the codes by means of affinity diagramming [34, p.12]. This was done in two iterations with the intention of discovering new categories since this could lead to insights. As each code was put on a digital post-it into Miro, the software chosen for affinity diagramming, there appeared to be no way of exporting these without paying for the software. Therefore another software, Figma, was chosen as a replacement. Overarching categories that were too general were also split into sub categories to allow for internal separation of codes (see Appendix B).
Establishing these categories allowed the authors to identify wants, needs, tasks and functions of the interviewees, but also allowed a relationship mapping between these as well as providing further insights into the field of BIM, 3D-viewers and space manipulation. The BIM field was new to both authors and the empathize phase was paramount in understanding the tool to be developed as well as its context. Furthermore, the interviews provided incomparable insight into limitations, possibilities and everyday interactions into how BIM coordinators use the related software. The results of the affinity diagramming would help us to identify possible features, situations and scenarios of XDI within the context of BIM management as well as providing a basis for a workshop session scheduled with a key stakeholder. Below are some of the key insights from the content analysis and affinity diagramming:

- It is important that information is multimodal. Complex information can be

put in separate areas in text whereas smaller pieces of information such as floor name, room size can also be put directly onto the model, directly mapped to what it aims at describing.
- Currently, collaboration on the same project is rare for BIM-coordinators. This is due to, among others, fiscal reasons but also because the existing tools do not allow collaborative actions.
- BIM-coordinators are likely to attend meetings with external stakeholders where floor plans and models are paramount. This is an area with potential for collaboration.
- Possible distinction: collaboration within roles and between roles
- There are those who prefer 2D (floor plans) to 3D (model) and vice versa. The system should allow for both.

Insights that validate the project:
- Users want one coherent software, currently functionality is spread across many different softwares.
- There are potentials for value in extending the functionality for spaces (projecting interiors, furniture, mapping sensor values).
- Desktop and laptop devices are the most commonly used. Especially when creating new spaces or making changes to models. Smartphones and tablets are more commonly used in the field for looking up information quickly and sometimes for auditing the models against the real world.
- Different devices have different capabilities in term of processing power and affordances (mobility, sensors, interaction techniques).
- BIM coordinators use different tools (devices) for different needs (processing power vs mobility).

5.2.1 Workshop Session With a Key Stakeholder

The next step in the design process was a workshop and feature defining meeting with a key stakeholder. Going into this meeting, our expectations were to establish common ground regarding feature specification, the scope of the tool and exploring the company's perspective regarding meta spaces. Mind mapping and relationship drawing on a physical whiteboard became a central tool for this. Here we were faced with an important delimitation for the scope of the thesis. The part of the tool that we were to focus on, would for instance not involve projecting furniture and interior design. Instead focus was directed towards the creation and editing of so called meta space and space containers. Here we were told that although the market is saturated with softwares for manipulating 3D models, there is no software that allows the user to create meta spaces and tie information to these in the way this tool intends to. Our attention then, was directed to finding geometries, and defining those as a space, but also the ability to tie information to these spaces. The meeting brought a deeper understanding of different hierarchies of spaces such as B-area, N-area (gross- and net area) and LOA (lokalarea in swedish, non-residential floor area translated to english). Furthermore functions and the data which these spaces would be related to but also a more detailed definition of the tool itself. The tool we are designing for is defined then as: a tool that allows users to create and

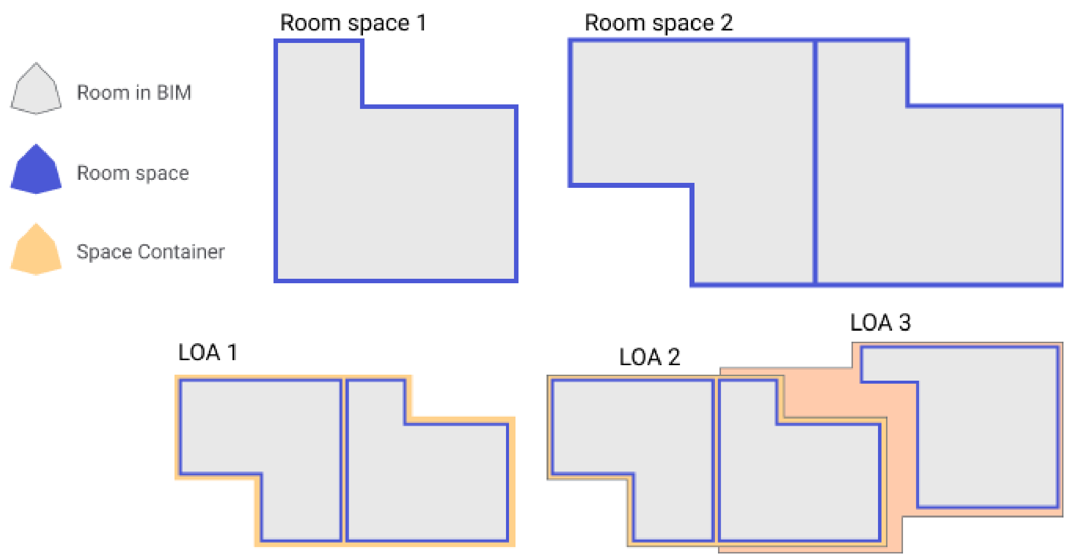

Figure 5.1: A visual representation of meta spaces and space containers (LOA).

edit geometries that represent physical space (meta spaces). The criteria were as follows: The smallest meta space is a room (called room space). There needs to be "room space containers" that sum the geometries of each individual roomspace. A user should be able to create, edit and remove a room space. A user should also be able to create, edit and remove a room space container. Meta spaces need to be able to hold data and data needs to be able to be added, edited and removed.
With these criteria in mind, we created flowcharts and feature maps to explore different flows that allow users to achieve the necessary activities with in the tool. This was done individually first and then collaboratively as we converged on suitable flows . We landed on two major paths: i) creating and editing spaces and their pertaining geometries (including deleting) and ii) adding and editing metadata (including deleting). These two are also intrinsically linked as when a new space is being created, users could also be able to add metadata to that space. Here it is likely that the mental model of the user will guide their expectations of the flow for creating new spaces. On one hand, spaces could be created by e.g. pressing a button "create new space". This would start a process wherein a geometry would be found and data points would be added. On the other hand, the process could start by defining a geometry and then saving that geometry as a new space. Which of these that is preferable is not something that can be solved using introspection but rather something that should be tested. For the first wireframe iteration, the latter, finding geometries first was chosen as a starting point.

5.3 Ideate

It is common in design processes to include an ideation phase. Activities in this phase are often centered at coming up with many different ways of solving a problem for the user. At least in the beginning of the design process or in the earlier iterations.

In the case of this thesis, we are exploring and designing for a tool which is part of an encompassing tool that is already in development. As such we have become part of an existing and ongoing design process and it would not make sense or be necessary to ideate the solution further. The problem and solution have already been identified by Sweco. In light of this, it seems weird to ideate possible solutions, since one already exists. Prior to the meeting with the key stakeholder, we planned on constructing user stories [72] and ideating on features as basis for a Kano Analysis [34, p.106]. The knowledge gained from this meeting rendered these unnecessary and we concluded that we would not carry these out. Our target shifted from constructing and ideating features that would to be included in the tool, to focusing on ideating and evaluating interaction techniques for interacting with the features of the tool. This affects the activities we perform in the ideation phase as these activities will instead be focusing on different implementations of the solution and the involved interaction techniques.

As stated in Design Process, despite exploring different implementations, the needs of the users will not change between designs. So all designs will necessarily have those in common. Despite this, there are many ways in which the designs can differ from each other. In order to ground the designs in the SOA as well as facilitate exploring the possible design space in a systematic way, some of these ways need to be detailed so that explicit decisions can be made regarding the implementation. One possible point of decision is the interaction techniques and input modalities the interfaces offers and uses. The taxonomy [63] provides an abundance of such interaction techniques. While there isn't time to test them all, at least some of them can be implemented within the scope of this thesis. Many of the techniques mentioned in [63] are based on exploratory research in which researchers come up with novel ways of interacting with digital content, making many of them unconventional. At the same time, literature on designing graphical interfaces [41] detail common interaction techniques with the warning that using interaction techniques other than conventional ones should only be done if the gain of doing so greatly surpasses the gain of using conventional techniques. Using Cooper's et al. [41] body of common interaction techniques complemented with rich data entry from [70] as well as the techniques from [63] we came up with a division that allows us to explore two different designs: *Conventional* and *Non-conventional* interaction techniques.

Initially we had a naive conception of exactly how much of the non-conventional design should be made up of non-conventional interaction techniques. While it is possible to replace all conventional interaction techniques, this probably isn't a very good idea. Point in case: we could replace rich text input by keyboard strokes with mapping letters to relative positions along the x and y axis of physical space (think moving the arm in a circular motion perpendicular to the body). Using sensors commonly found in smartphones, positions could be recorded and corresponding letters would be inputted into the selected text-field. While possibly novel, this kind of interaction would probably not adhere to the warning about replacing what already works stated by Cooper et al. [41]. So the non-conventional design, by necessity, needs to have some conventional interaction techniques too. The question then becomes: how much? Here context becomes relevant. Impractical ways of interaction might be better suited for installations at exhibitions than workplaces where pro-

Conventional Interaction techniques across input modalities		
Multi touch gestures [41]	***Pointer*** [41]	***Rich data entry physical and digital keyboards*** [70]
Tap to select	Pointing	Click / Tap
Activate	Clicking	Click / Tap and hold
Toggle	Click and point	Multi click / Tap
Tap and hold	Click and drag	
Drag to scroll	Double click	
Drag to move	Chord clicking	
Drag to control	Double click and drag	
Swipe up / down	Mouse up and mouse down	
Swipe left / right		
Pinch in / out		
Rotate		
Multi-finger swipes		

Table 5.1: Conventional interaction techniques, listed by their categories proposed by Cooper et al.[41] and Wikipedia [70].

ductivity is key. With this is mind, it was decided that non-conventional interaction techniques should only be implemented where they could provide value in the form of a better user experience or increase the usability of the interface. Furthermore, this thesis is mainly concerned with cross device-interaction. And so we focused our efforts on exploring interaction techniques for cross-device functionality.

5.3.1 Sketching

After the flows and functions were determined, the two of us started sketching on different implementations. This was done for mobile first, on paper. Sketching was done in a parallel prototyping manner [34, p.122] to explore different implementations. In total two iterations of sketching were conducted. After each one, we converged to explain our designs and merged the two prototypes into one. This was done by taking digital photos of the paper sketches and uploading them into Figma. Here screens could be ordered to visualize the flow of interaction. By transferring the sketches into figma we could also easily share our designs with each other since by this point we were put in voluntary quarantine due to the corona pandemic. Another benefit of putting the screens in Figma is that it allowed us to enhance or edit the sketches quickly by putting shapes and text over and around the image.
In order to be able to test the flow, we extracted tasks from the flow and feature maps constructed. These were:

- Create a new room/container space
- Remove a room/container space
- Add a room space to an existing (container) space
- Add a data point to an existing space
- Remove a data point from an existing space
- Edit a data point from an existing space
- Show all spaces for a given floor
- Show all spaces
- Show one space across all floors

- Show one space, across one floor
- View a space that spans several floors

We then performed cognitive walkthrough [34, p.32] on the merged design to see if all tasks could be completed with in the design. This gave us a list of items for the next iteration which it would need to encompass to better allow for the completion of the tasks.

For the second iteration, again, sketching was done on paper. After that we converged in a manner similar to the first iteration where photos of the screens were put into figma and then cognitive walkthrough was conducted. By this point we had validated that the flow and functions were sufficient to complete the tasks and that the merged screens from iteration two were a good starting point for wireframing.

5.4 Prototype

In order to be able to test these interaction techniques for cross-device interaction with the evaluation methods provided in the SOA, a system of interfaces needed to be wireframed. This system was realized as one interface for mobile and one interface for desktop. These are common devices in office environments that all users are expected to own. Not designing for tablets was motivated by the fact that tablet interfaces to, some degree, often resemble mobile interfaces. Tablet and mobile devices also share other key characteristics such as being physically mobile i.e. they can be moved around while still being functional. Compare this to desktops where the user is either limited to a static workplace, desk or forced to carry around a laptop with enough computing capacity for manipulating large 3D models. With this reasoning, we concluded that it would be more interesting both from an interface perspective to design for devices that could be considered opposites given our context while also challenging ourselves when designing XDI techniques.

We aimed at a medium level of fidelity in the wireframes, sufficient to make UI items discern- and identifiable across systems while still maintaining velocity in prototyping and iterating. There is some disparity between the levels of fidelity between the interfaces. This is partly because we did not create a graphical profile, one wasn't needed, despite this stylistic choices are made. This is largely unavoidable as the design grows and different styles, techniques and solutions are explored.

The tool for realizing the prototype was Figma, since it allows us to work collaboratively in a synchronous manner, in the same project, as well as spectate each others views. This was beneficial since by now we were in quarantine and recommended to work from home. Figma also allows the designer to create interactive prototypes letting users navigate a series of screens as if it were an actual interface with animations, while also enabling them to simulate backend functionality.

The mobile interface was wireframed first, following a mobile first approach [61]. This made sense from a pragmatic point of view as the encompassing tool as a whole is being designed mobile first too, therefore the prototype for the whole tool could serve as inspiration for the part we were designing for. At any case, the tool we design would be accessed from within that prototype which provided some context for our tool. The same functionality was then designed for desktop. Finally the points of cross-device interaction between these two interfaces were designed.

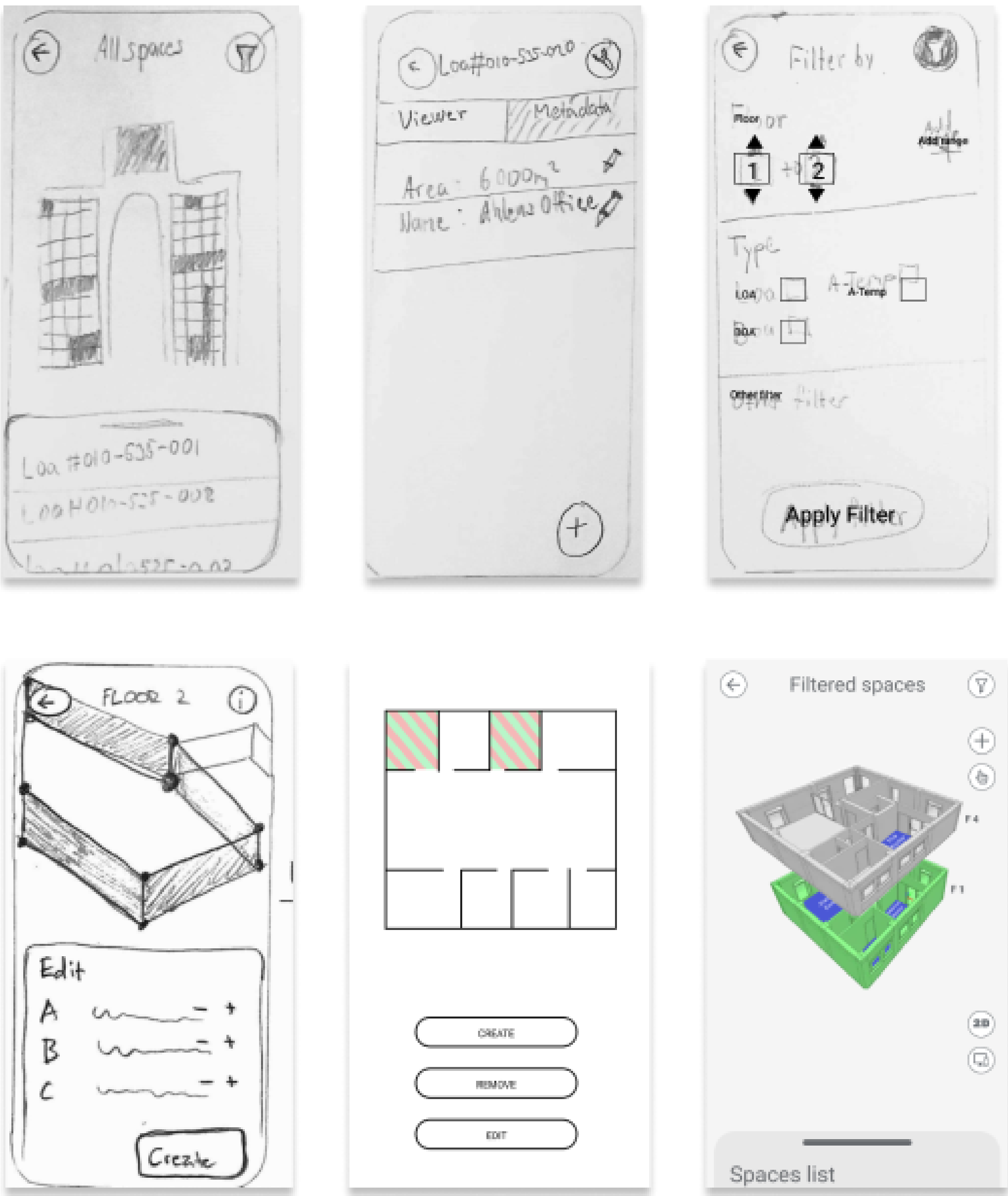

Figure 5.2: An excerpt from the evolution of sketching sessions leading up to the digital prototype.

In a way the interfaces on their own serve to create a context for the cross-device interaction to exist in.
In the Design Process section 3.5, we outlined that separate designs should be explored. As mentioned we had also hoped that this would be realized by exploring different interaction techniques, letting these guide the design of the interface. But because a fully non-conventional design wouldn't be very practical, the parts of the interfaces that does not concern cross-device interaction were reused. This led to a significant overlap between the conventional and non-conventional designs. This does not necessarily affect the thesis. Different designs have been explored at the interaction technique level, a smaller scope than originally intended. It should be noted that the XDI is not confined to interaction for switching between devices. Indeed, attributes such as semantic (phrasing) and perceptual consistency (look and feel) need to permeate throughout the interfaces. These are however areas which are not necessarily subject to the problem of local maxima. Wording and look and feel can be consistent regardless of the choice of UI items and flow. At the same time, creating one system of interfaces proved to take more time than anticipated, as such our proposed Design Process would perhaps be better suited to separate teams working on separate designs, at least for the prototyping phase.

5.4.1 Iterations

It is awkward to divide the wireframing process into iterations because in reality we continuously tested the designs against the tasks extracted (using cognitive walkthrough [34, p. 32], mentioned in detail below), as they took form and new screens were added and changed in response to this. Still there are some milestones which are worth mentioning. These milestones are denoted by an evaluation either by a key stakeholder or other individuals who had not previously seen the interfaces. Iterations not mentioned further in this thesis were evaluated using cognitive walkthrough.

5.4.2 Mobile 1.0

Functions of the Mobile 1.0 included navigating the 3D-viewer, creating new spaces and adjusting the geometries before saving and also previewing, editing and removing metadata. We also included a filter function for selection of specific floors and floor range selection.
In figure 5.3, the utmost left screen can be likened to a "home screen". When users enters the tool, this is what they are presented with. It is an unfiltered view of the building at hand. Do note that the images used for the "3D viewer" element of the screens are arbitrary and does not relate to any real building or project tied to Sweco. They are there simply to signify that there is a 3D model to be interacted with and at some points act as points of interactions within the prototype. Note the spaces list card which can be pulled up from the bottom of the screen. Here are the spaces created in the model, ordered according to the floor they belong to. The middle left screen shows a filter screen where users can filter away floors which are not relevant as well as filter on the kind of spaces they want to view. The

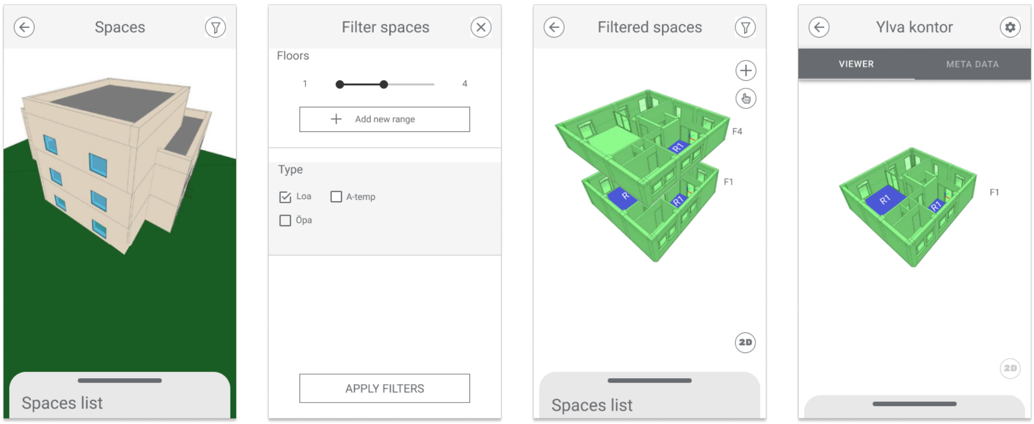

Figure 5.3: A selection of screens from the first iteration of prototyped functionality in the mobile UI.

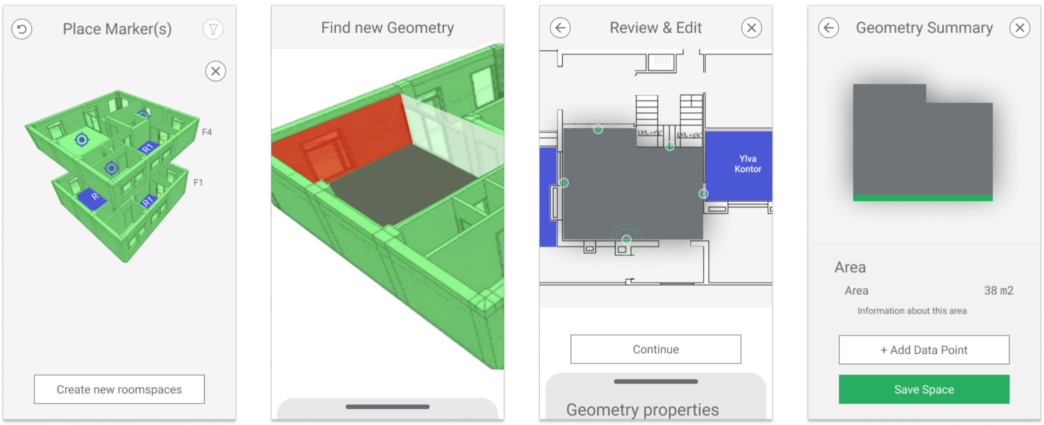

Figure 5.4: A selection of screens from the second iteration of prototyped functionality in the mobile UI.

filter affects both the spaces list as well as the view of the 3D model, as seen in the middle right screen. The right screen shows the view from within a space. The screen provides a tabbed view for viewing the 3D model of the room or looking at the related metadata which the space contains.

Figure 5.4 Shows how to find a new geometry and save that geometry as a new room space. The user places a marker somewhere in the first screen and presses continue. The tool then calculates that area and presents the user with an interactive overlay that represents that area in a 2D view of the floor that the space is being created in. Here the user can make adjustments to the area as they see fit, as shown in the third screen. Finally the user saves the geometry as a new space.

In Figure 5.5, The user has entered one of the spaces available in the model. Besides switching between the viewer and metadata tabs, the user can create and edit metadata for that space, as seen in the two screens on the right.

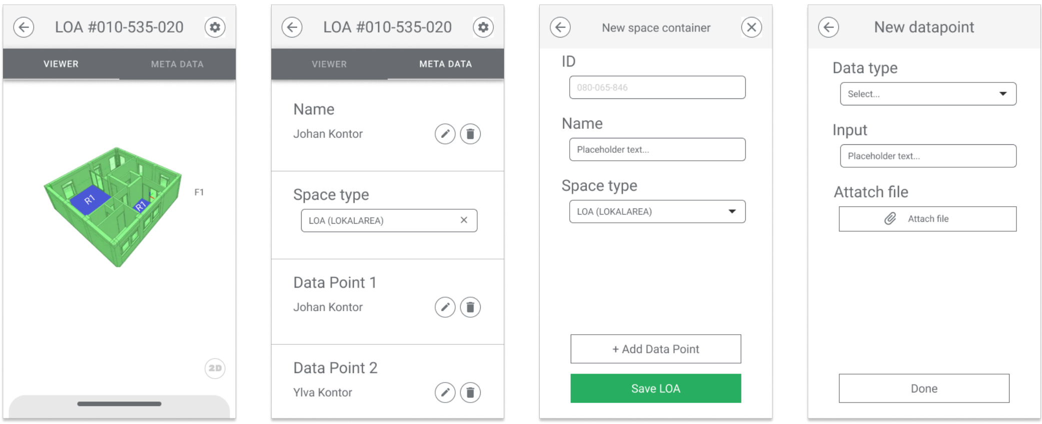

Figure 5.5: A selection of screens from the third iteration of prototyped functionality in the mobile UI.

5.4.3 Mobile 1.1

The first evaluation revealed that the tool needed functionality and screens for finding new geometries and adding these to already existing spaces. This was done by making users choose between saving a new geometry as a new space or adding it to an existing one, when a new geometry had been found. Furthermore, a search bar was added to the filter screen for quickly looking up specific spaces. The evaluations also revealed that there needed to be a way to remove applied filters.

The bottom cards holding information as well as the metadata section were re-designed. This was done with respect to the gestalt laws as a guiding hand for separating and relating data points. The evaluation also revealed a problem with creating space containers. It had been assumed that these were identical to regular room spaces, where the geometry was made up of the room spaces it contained. But because room spaces can have varying types e.g. LOA or A-Temp, the type of the room container is ambiguous. Thus, the act of creating space containers need to be somewhat different than creating room spaces. This was realized by letting users enter a mode where they can select one or more existing room spaces and the continue on to make a space container that contained these. Other changes to the interface include re-mapping the floors in the spaces list so they relate better to the 3D model, and potentially the mental model of users. This meant changing the direction of the spaces list (in the bottom card) so that the highest floor is at the top of the list, corresponding to the highest floor in the 3D model.

Again evaluation was conducted using Cognitive Walkthrough [34, p.32]. This time, this involved a stakeholder at Sweco. The results indicated that we had reached a sufficient level of fidelity and that functionality was designed such that the list of tasks could be completed. As such, we moved on to designing the desktop interface.

5.4.4 Desktop 1.0

Following the mobile interface, the first desktop iteration concerned translating the functionality and flow from mobile. Because of the larger screen real estate, we

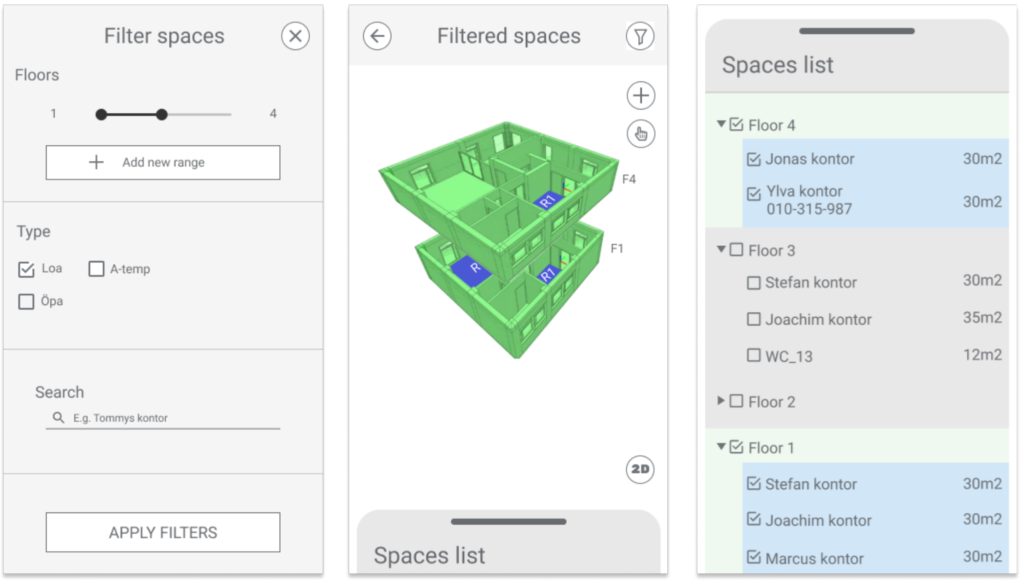

Figure 5.6: The filter screen displaying floor range selection with the possibility of adding new ranges, as well as category and search capabilities (first screen) and the 3D-model viewer and the related spaces list (second and third screen).

could "move" interaction that was previously hidden due to lack of screen estate out where it is always visible. Still we wanted to maintain the viewer in the background and UI items around it and cards that hold information. At the same time the information must be visualized in a way which makes sense from a desktop point of view.

Figure 5.7 show a common screen from the desktop interface. The app bar from mobile was translated to an independent bar which keeps a title. This title announce the state of the interface as well as the filter function.

Controls for the spaces list card was put into a floating panel (the left panel titled Spaces list) which can be moved and minimized. In mobile, looking at a specific room space required moving to a different screen. In Desktop, this information is also moved into a panel, the 'space' panel to the right in Figure 5.8, which is visible on the "main" screen. The spaces list panel, the 3D model viewer and the space panel are connected by the data that is displayed. The spaces list is a representation of the viewer in text form. The selected room, Ylva kontor, in the spaces list is also highlighted in the viewer. By selecting a room in either the viewer or the spaces list, the information for that room is also displayed in the space panel. The ability to "turn on and off" information in the viewer was added in desktop. This functionality can be seen in Figure 5.9. By toggling any of the three buttons to the right, users can enable or disable that information in the viewer. Currently these include the floors numbers, the room names and the calculated area for the geometry in a given roomspace.

This iteration was evaluated using Cognitive Walkthrough. The results indicated that the functionality and flow were adequately implemented.

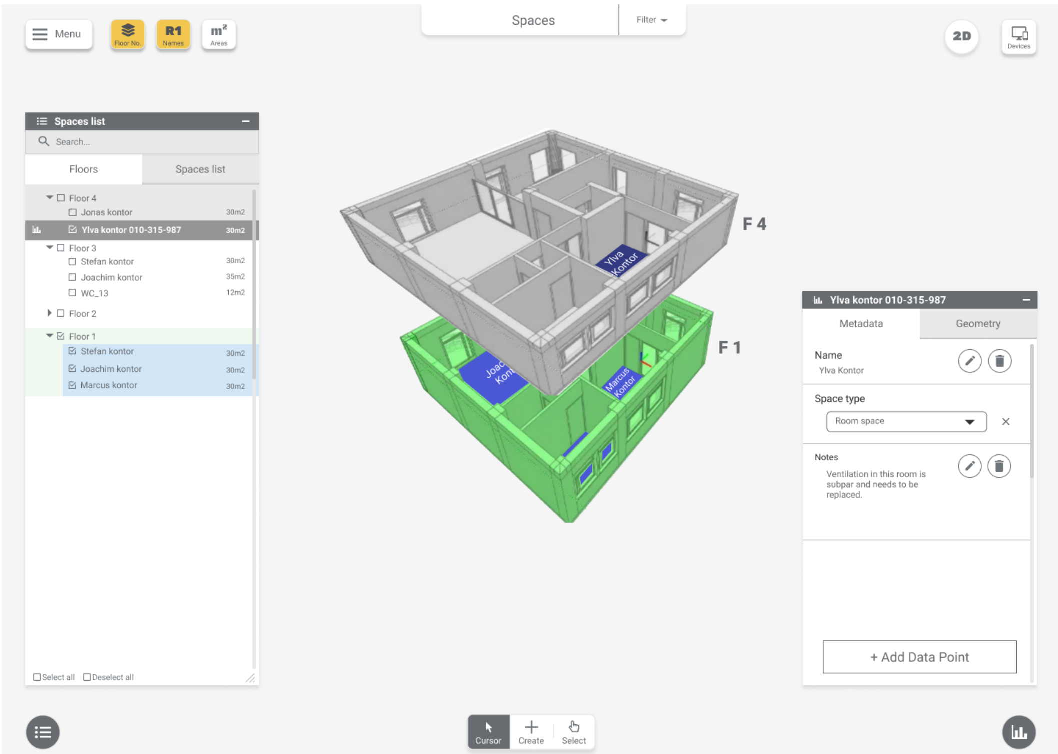

Figure 5.7: The dashboard and start screen for the desktop UI.

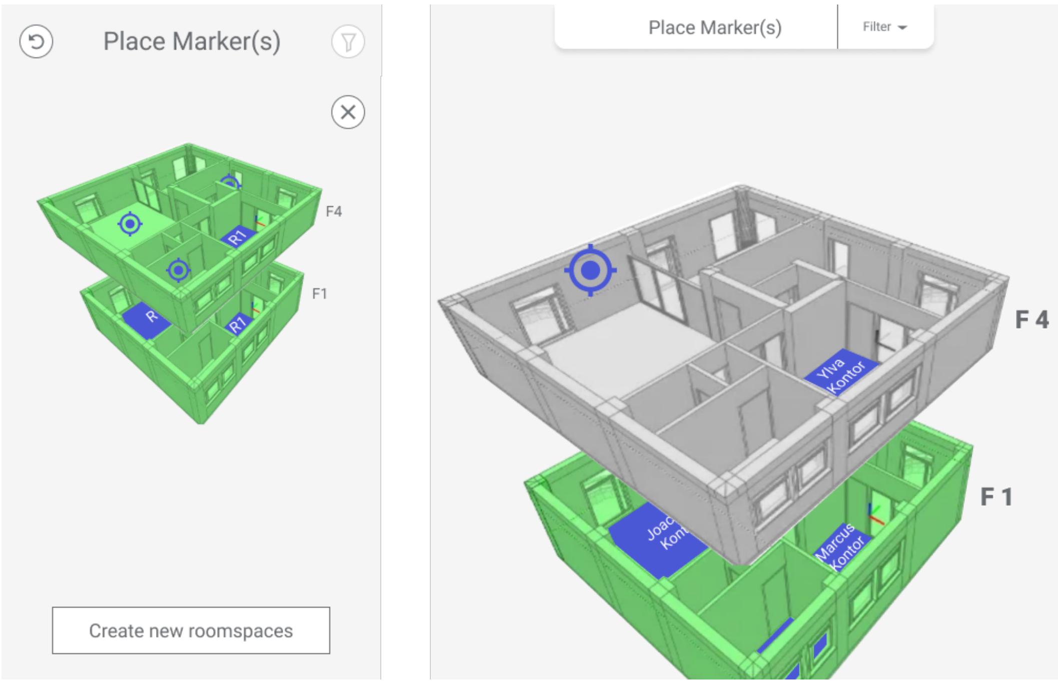

Figure 5.8: Text representing the state of the system. Here displayed in the top of the screen as "Place Marker(s)".

5.4.5 Mobile 1.2 and Desktop 1.1

Following the completion of both the mobile 1.1 and the desktop 1.0 interface, it became clear that these two needed to converge and that some desktop features would need to be propagated back into the mobile interface. These included changes to icons, wording and the filter function. At the same time the possibility for new functionality was made evident as we consulted the key insights resulting from the interviews. These inspired interaction for looking at the model in 2D as shown in Figure 5.10
Other changes included a different way of adjusting geometries when creating and editing spaces, and more clear mapping of text and buttons based on feedback from stakeholders and supervisors. We also made effort to improve the feedback regarding the state of the system. This was done in the top of the screen on both mobile and desktop.
As a another result of feedback during evaluation, we discussed the fact that the text in the system of interfaces was presented in english. This could be a potential pitfall when evaluating potential end users. We decided to not translate the interface into swedish, based on two main points. Firstly, the project as a whole is being developed in English. Secondly, English is prevalent in the existing tools that are currently being used at Sweco. Translating this terminology would create challenges such as translating “room spaces”. This would for instance be translated to “room room”. Furthermore, by keeping the terminology we could communicate with stakeholders more readily.
Each of the interfaces needed to be able to scale to big buildings including many floors. Including many “within tool” created spaces visible at the same time and the possibility of having single floors spanning thousands of square meters. Within the scope of this project, we chose not to prototype this scale since the goal of this would be to evaluate that interface in itself rather than the means of cross-device interaction between devices. Therefore we decided that the current state of the interfaces sufficient for introducing and evaluating cross-device interaction.

5.4.6 Connecting the Interfaces

At this point, with both the mobile and desktop interfaces sufficiently wireframed, the next step was to create the cross-device interaction between the interfaces. Again we consulted the key insights from the interviews and the workshop with the stakeholder. With these insights and the interfaces as a context, we bodystormed [34, p.20] different kinds of cross-device functionality. In the end we settled on what would be called *share view* and *continue on other device*. The former is based on the fact that BIM models are extremely vast and complex. Navigating the model

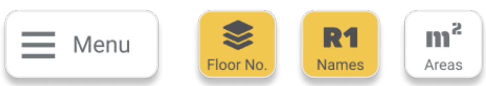

Figure 5.9: Global controls for toggling information displayed onto the 3D model on and off.

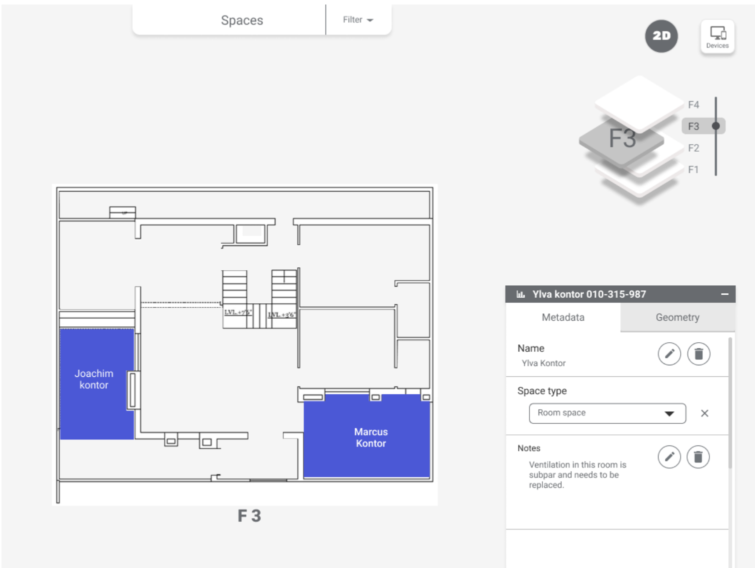

Figure 5.10: The UI for displaying a 2D-layout of a floor and the controls for selecting adjacent floors.

to where you need to work can be time consuming. To solve this we entertained the idea of sharing one's position in the model as well as in the tool. Because the tool will be built using web technologies (Angular [68]) we thought of a users position in the tool and model as a state which can be described as a javascript object. Sharing one's view would then be analogous of copying the sender state and bringing the receiver state in to the exact same state. A metaphor would be telling students to turn to page 9 in a book, the result is several different books in the same state. One consequence of this is that there is nothing stopping users from diverging from that state once they've been taken there. This is useful for collaboration where many people are working parallely in the same part of the model but with different tasks as opposed to screen sharing where receivers are passive observers, i.e. connectivity is sporadic. Furthermore, because connectivity is sporadic, no synchronicity is required for the states after the transfer (n.b. by no synchronicity we do not mean possible cloud synchronisation of the model or other synchronisation such as the canvas in Figma).

The second cross-device functionality is based on different devices having different capabilities. If a user is working on a device and finds herself limited by the affordances in the current device, the progress should not be lost. While autosave functions are common in e.g. Word and again Figma, what is saved is often what's on the canvas or in the document, not menu or tool choices. The state of the software, then, is not saved. If I am working in Word with bold text and the search bar showing and continue writing the document on another device, those settings will not be transferred. Typically these can be user settings but in our interface, there are workflows which are more complex where auto saving before a certain step does not make sense. For example, when a user creates a new space, the user first needs to bring the tool into creation mode by pressing a button. Then the user needs to place a marker and press "Find new geometry". When a geometry has been found the user needs to audit the geometry against the model and enter obligatory information before the space can be saved. What if the user finds themselves unable to go to the next step because of some unforeseen event, should they have to abandon all progress and do it all over on another device? By now, the obvious answer is no. Keeping the idea of states from *share view*, we wanted to preserve the progress and transfer that to another device. We say transfer here instead of shared or copied because if both receiver and sender continue working on the same progress state, there is no way of knowing which one is the right one. Ultimately users might end up with two very similar spaces where only one is intended. The solution to this would be to have a continuous connection between the sender and receiver and synchronize the changes to the state between devices. In the current implementation the state is transferred from the receiver device to the sender device. Bringing the sender back to before they started creating a room and the receiver into the the progress state.

5.4.6.1 Conventional

When it came to the conventional interaction techniques we consulted the body of conventional interaction techniques [41] as well as those found in [70]. Again, there are many possible implementations and in order to make an informed first pick we looked to Chong and Gellersen [30] who conducted a study on user-defined actions for device association in which they let subjects define actions for pairing devices. For this, subjects were provided with several prototypes of real devices with the task to show how a connection could be established between them. Chong and Gellersen then calculated the frequency for each action (how many times the same action was defined) as well as mapping out the frequency for different device combinations. The most common action was "search and select" with 165 mentions out of 752 subjects (across all combinations). Furthermore search and select was prevalent within each device combination except for Tablet Computers (Button Event had a frequency of 41 and search and select a frequency of 40) and Interactive Displays. Because Interactive Displays are not within the scope of this thesis, the lower frequency for search and select here does not affect the validity of search and select in our context. Both cross-device functionalities were placed together in the interface in what we internally called Cross-Device Handover Point (CDHP). This is represented as a series of UI elements that make up the search and select implementation of associating devices. Figure 5.11 Shows how users access the cross-device functionality on desktop interact with the cross-device handover point. The button in the top of Figure 5.11 shows the CDHP button which is always visible to the user. The orange badge alerts the user that there are new incoming XDI requests from other users. If there are no alerts, the badge does not show. In the middle of Figure 5.11, the CDHP is shown as a menu where users can choose to either *Share View* or *Continue on other device* or manage incoming requests from other users. If there are no requests only the incoming requests heading is displayed. The two menus in the bottom left in Figure 5.11 show different states of the same menu, *share view.* Users can select however many devices or other users they want to send the view to. Selections are marked with a check-mark. As soon as one selection is made, the share button becomes enabled and the user can share their view. The two menus in the bottom right in Figure 5.11 show two different states of the same menu, *continue*

Figure 5.11: The conventional CDHP UIs for desktop-to-mobile.

on other device. Again users select whom they want to send their progress to and their selection is marked with a check-mark. However, only one selection can be made and further input is disabled. Despite the fact that *share view* and *continue on other device* are similar, there are three distinguishing features to discriminate between them. The header on the top of the menu, the behavior of placing check marks and the text on the button to complete the process.
The UI items for cross-device interaction on mobile are similar to those of desktop as seen in Figure 5.11. Again users access the CDHP via a button. This is true for all screens where the 3D viewer is visible. In screens where the viewer is not present, access to the CDHP is moved to a drop down menu accessible from the upper right corner, seen in the top right in Figure 5.11. This is because the button interfered with other UI elements on those screens. Other than this, the largest difference is that upon selecting either *share view* or *continue on other device* the user is taken to a separate screen for the remainder of the process rather than shown another menu as in desktop. Note that these screens behave identically to how the corresponding menus work in desktop, shown in Figure 5.12. Check marks are displayed upon selection, buttons are disabled until a selection has been made. Furthermore, selection of receivers is disabled for the *continue on other device* screen when a selection has already been made.

5.4.6.2 Non-Conventional

The taxonomy [63] provided an overview of interaction techniques for different phases of the cross-device interaction. As previously mentioned these were divided into three phases: a) Configuration, establishing a connection between devices; b)

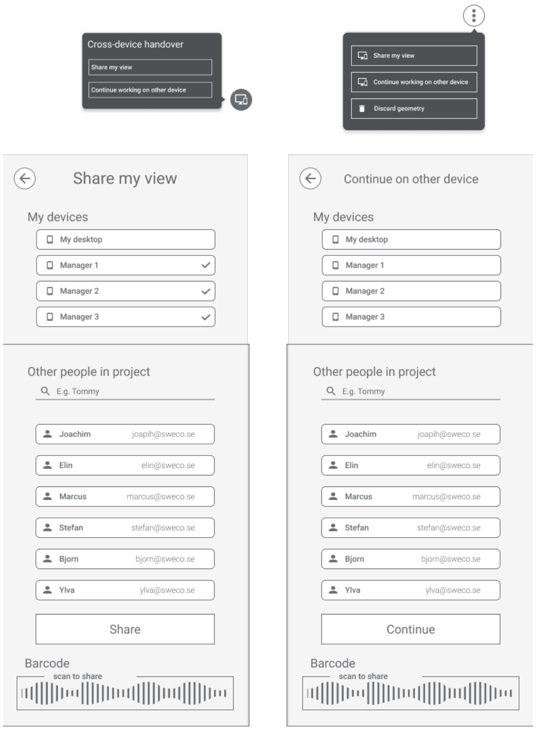

Figure 5.12: The conventional CDHP UIs for mobile-to-desktop.

content engagement, viewing, editing, sharing otherwise manipulating data across devices; and c) disengagement, aborting the connection between devices. Because of their multiplicity we needed to narrow down the possible choices. We started by eliminating groups of techniques which were either irrelevant or impossible to implement. The entirety of phase three was left out since it regards techniques for device disengagement and implies continuous connection which does not apply to our implementation. In Brudy et al. [63], Interaction techniques were also put into categories based on their input modalities, On-screen | Touch, Around Device | Gesture, Device Motion 2D | 3D, Shape change, and Body Gestures. Out of these Around Device | Gestures, Shape Change, and Body Gestures were eliminated on the grounds that it is apparent that they rely on hardware not readily available or involves manipulating the physical form of the device e.g. Bending [63, p.61]. This left us with 72 interaction techniques. For elimination among these, we established six criteria which the techniques had to fulfil to be regarded as viable. The first criteria being that the selected interaction technique had to be clearly distinguished from those defined as conventional (see Table 5.1). The second criteria that the technique should, to some degree, be testable and plausible to carry out (within the bounds of this thesis). The third criteria was that techniques need to allow for transference between different kinds of devices e.g. desktop-to-mobile, mobile-to-desktop. The reasoning behind this was; by letting all evaluators transition between devices, we maximize the number of evaluators for each interface. The fourth criteria was that techniques cannot rely on technical dependencies which are not readily available to users and stakeholders. Examples of these include wearables such as smart watches, tabletops, RGB camera lamps, depth cameras and similar external equipment. The fifth criteria was that when several techniques are presented in the same paper and one performs better than the others, the top performer should be chosen and the others eliminated. The sixth and final criteria, which was optional, aimed at choosing interaction techniques that somehow could enable knowledge transfer between the interfaces i.e. if a user learns to do something on desktop, they also know how to do that thing on mobile.

Based on these criteria, only five made it through; Drawing [30], Synchronous tapping [10], Synchronous gestures [24], Snapping a picture pair [30] and Shaking [7] [16] were considered as candidates. Out of these, drawing was eliminated on the grounds that drawing on the screen without also interacting with the 3D model on screen would be hard on mobile since this would have required deactivation of the 3D model maneuvering or otherwise increased navigational excise. Synchronous tapping and synchronous gestures were eliminated because they rely on a 1...1 x 1...1 relationship or possibly 1...2 [63] since one person can only reasonably tap two devices in a synchronous manner at any given time. This left us with: *Snapping a picture pair* and *shaking*.

Snapping a picture pair requires that a device affords taking pictures or otherwise scanning barcodes. For our intents and purposes this makes this interaction technique unidirectional in a from desktop-to-mobile fashion. Users can only use the interaction technique when transitioning from desktop-to-mobile. This is a practical limitation however and we decided that there is no reason why all devices should not be able to display barcodes, mobile to mobile is a very likely use case. As such, both desktop and mobile were fitted with barcodes. The idea then is that when a user wants to share their view or continue on other device, they go to the CDHP where the relevant barcodes are displayed. For mobile, the option to scan a barcode was also added. The research on snapping a picture pair [30] suggest two pictures to be taken (a picture pair), where we design for only one, whilst having the other device display the barcode. This decision makes sense in our setting and is in line with the purpose of transitioning between devices. Snapping a picture pair, i.e. two pictures across both devices, did not make sense and would introduce an extra and meaningless source of interaction.

In the case of shaking, the research refers to this as placing devices in close vicinity of each other while establishing a connection by synchronously shaking them [7]. However, some adjustments had to be made here as well when adapting it to this project. Only one of our selected devices is able of being shaken. This implies that the only direction where shaking is possible is when transitioning from mobile-to-desktop. There is in fact no reason that shaking as a XDI technique should not allow for synchronous shaking as well, but it can not be dependent on this in situations other than mobile-to-mobile transitioning. This setting will be left out of the scope of thesis due to us not covering that interaction transition. By this reasoning, shaking also becomes unidirectional. At this stage it should be noted that both selected interaction techniques are unidirectional. From a prototyping technical point, these interaction techniques needed to be implemented as separate groups of screens i.e. both scanning barcodes and shaking is not possible from within the same set of screens. In reality this limitation would not exist and there is no reason for them to be mutually exclusive options. Figure 5.13 shows the CDHP for

Analysis and elimination of Non-conventional interaction techniques		
On-screen | Touch		
Corresponding gestures	X	Worse performance than "pick and drop" [14]
Dragging	X	Conventional (Cooper) [41]
Drawing	X	Hard to draw on mobile [30]
Finger postures	X	Depends on smart watch [49]
Flicking	X	Conventional (Cooper) [41]
HyperDrag	X	Depends on Camera based object recognition [5]
Painting on surfaces	X	Variation of "Drawing" [30]
Pantograph directing	X	Worse performance than "pick and drop" [14]
Pick-and-drop	X	Dependent on digital pen for cross device handover [3]
Pinch, swing	X	Conventional (Cooper) [41]
Pinching	X	Conventional (Cooper) [41]
Pointing	X	Conventional (Cooper) [41]
Slingshot targeting	X	Worse performance than "pick and drop" [14]
Stitching	X	Depends on smart watch [39]
SuperFlick	X	Depends on tabletop [15]
Swiping	X	Conventional (Cooper) [41]
Synchronous tapping	X	Depends on two users or one user manipulating two devices [10]
Tapping	X	Conventional (Cooper) [41]
Vision-based handshake	X	Depends on computer vision [17]
Device Motion 2D | 3D		
Bumping	X	Only possible Mobile → Mobile [8] Depends on tabletop [43]
Placing down device	X	RGB Camera Lamp [45] or computer vision [17]
Recognizing motion correlation	X	Depends on external tracking [47]
Shaking		[7] [16]
Snapping a picture pair		[30]
Stacking	X	Only possible Mobile → Mobile [36]
Synchronous gestures	X	Depends on two users or one user manipulating two devices [24]
Around Device | Gesture		
Body gesture	X	Depends on depth cameras [29]
Dragging content in negative space between devices	X	Depends on tabletop [43]
Drawing a line on the surface between devices	X	Only possible Mobile -> Mobile [42]
Grasp and micro-mobility: fine-grained reference, hold to refer back	X	Depends on Kinect cameras [33]
Lift-and-drop	X	Depends on top-down stereo camera [25]
Pick-and-drop with gaze	X	Depends on Eye tracking equipment [46]
Point-and-grab	X	Depends on Kinect-sensor [59]
Pointing with phone, touch and drag, release touch to stop	X	Depends on depth cameras [29]
Propagation through f- formation	X	Depends on Kinect cameras [33]
Selection with gaze	X	Depends on Kinect cameras [33]
Touching the surface with edge of device	X	Depends on interactive surface [35]
Wave-out and wave-in muscle sensor gestures	X	Depends on Myo wearable armband [53]
Waving above	X	Depends on smart watch [49] or RGB Camera Lamp [45]
Waving between	X	Depends on sound [40]

Table 5.2: Analysis and elimination of Non-conventional interaction techniques, with motivations.

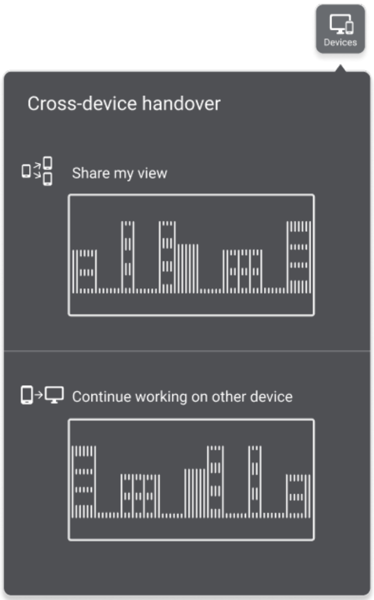

Figure 5.13: The barcode showing the non-conventional CDHP for desktop-to-mobile.

barcodes in desktop. The user need only to press the Devices button and the rest is done on the receiving phones. For the *share view* function this distributes the majority of the workload to the receiver rather than the sender. This could prove to be useful in 1...1 x 1...1 situations with many participants. Rather than having to look up all people at a meeting, all those who needs the shared view simply scan the barcode.

The mobile interaction for *share view* is shown in Figure 5.14, here, as the user enters the CDHP, they are provided with the barcodes for the device itself as well as a scan barcode option. When the user taps on the scan barcode button, their smartphone camera is activated with a crosshair visualizing the area which needs to target the barcode. As the system detects a barcode, the Scan button is enabled. After scanning, the incoming view is displayed. Note that the sender view remains unchanged after it has been scanned.

The screens are virtually the same for *continue on other device*. The difference lies in what happens after the barcode has been scanned. As stated in Cross-Device Interaction above, the current implementation requires the sender view to revert to the state before the progress. As the system recognizes that a barcode has been scanned, the sender device is sent back to that previous state and the receiver device is put in to that state instead. This way there will only ever be one user in a given progress state.

When transitioning from mobile-to-desktop in NON-CON scenarios, shaking simulated by screens showing a shaking mobile onto the screen. The mobile screen was animated as moving from left to right five times in quick succession, upon which the user was faced with the screen for selecting devices.

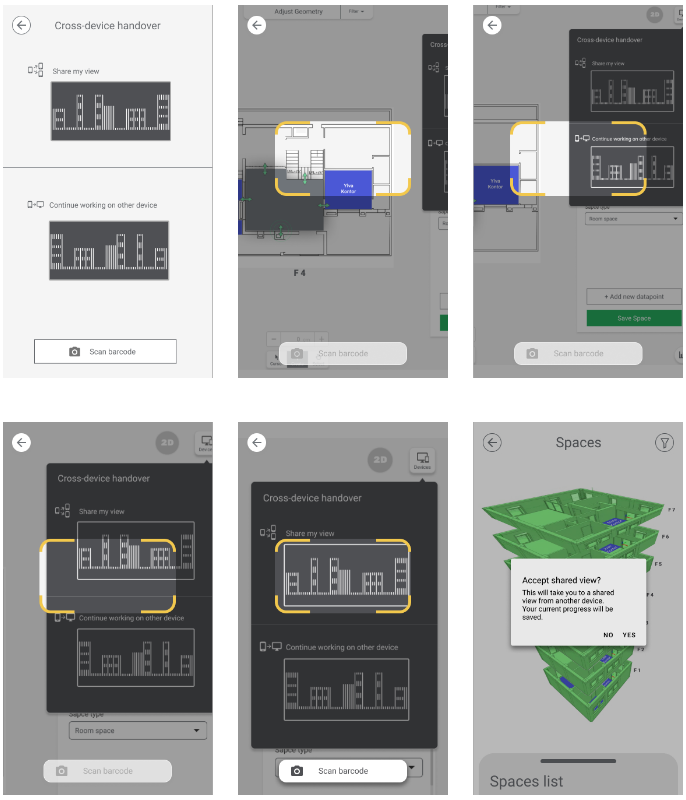

Figure 5.14: An attempt of showing the animation for simulating scanning a barcode and transitioning desktop-to-mobile.

5.5 Evaluate

For the final evaluation, several measurements were made. Two different sets of survey questions were used, STS for measuring the experience of the transitions betweens devices and CPUS for measuring the perceived usability of the cross device interaction. Furthermore usability was measured both quantitatively and qualitatively by usability testing using CTA ([34]). Lastly, the tool maze.design provided some usability metrics in the form of completion times for tasks (TTC), heat maps for clicks and the time spent on each screen (maze.design is detailed further below).

Due to the corona pandemic, evaluations had to be conducted remotely. In a non-pandemic world, we would have conducted the evaluations in person. This would have affected the design of the evaluations in a number of ways. Firstly, in person we could have set up the evaluation such that the users could test each interface on their native devices i.e. mobile on a smartphone and desktop on a desktop or laptop. Remotely this became harder to realize. Secondly, we needed a way of observing the user in real time online, since this could not be done i person. Lastly, because the project we are working on is a product in development, information about the project or parts of it, are sensitive in nature. This, in combination with being bound to remote solutions, meant the prototype could not be tested on potential end users.

5.5.1 Maze.design

In regards to data collection, we considered different options. Firstly, the prototype mode in Figma. With screen share and observation, we could conduct usability testing [34, p.194] using think aloud [34, p.180]. However, we also wanted to use the survey questions, CPUS and STS, detailed in Section 2.6. This could have been solved using an external tool like Google Forms or other online survey tool. This does however increase complexity in the execution of the evaluation. After researching different alternatives for usability testing online we found Maze.design [74]. Maze is an online usability evaluation tool that allows designers to create so called mazes. These mazes are a series of blocks or activities which the user is to perform. These blocks can either be missions; a series of expected paths with a task description, or different kind of survey questions. As a user completes the maze, data is collected regarding the interaction, including clicks (represented in the form of heat maps), paths through the prototype, the answers to the survey questions and completion time. Number of direct and indirect mission completions and fails are also recorded. Maze further allows providing participants with context screens and instructions as well as an end screen in which a new mission-, context- or instruction screen would guide the participant to the next task. A mission could also be separated into smaller task, with instructions readily available one click away accompanied by an onboarding process on how to display these throughout a mission. This let us share just one link, where a participant could complete several missions in a carefully designed order, complete related questionnaires whilst also guiding them throughout the evaluation directly in their web browser of choice.
Despite this, Maze has some shortcomings. At the point of designing the mazes, our project outgrew the loading capacity in which Maze store projects. This resulted in the error message “payload error” which forced us to divide the project into smaller projects. Practically, this meant that we had to present participants with conventional and non-conventional missions and paths separately, without the option of interweaving these. See Section 5.5.2.1 below for full details regarding Maze presentation order and the design of data collection.

5.5.2 Designing the Evaluation

It is commonly accepted that usability tests need not include more than five users [6]. This is based on an assumption of diminishing returns where the an increase in users that tests a design with a finite amount of usability problems will yield an increasing overlap in problems found and a decrease in new problems found as the number of testers increase. Nielsen [6] state that ca. 85 percent of errors can be found by testing with five users. This is helpful since evaluators are in many cases a scarce resource. However, there is some critique to this, Matell [55] highlights the dangers of making very strong generalisations on a large populus with a small sample size. This is a common area of discussion in more scientific areas where statistical tests are used to measure the effects of dependent variables. This thesis does not aim to generalize on a larger population using the results from the evaluation. Therefore it is not likely that adhering to Nielsen’s [6] recommendation of 5 users will harm the quality of this thesis.

Aiming for five evaluators then, this evaluation will test two interfaces in a system, connected by the Cross-Device Handover Points and interaction techniques detailed above. Despite being one system, each interface is likely to bear its' own problems. Because of our efforts of allowing for knowledge transfer, through the guidelines provided in the SOA e.g. semantic and perceptual consistency and functional symmetry, there is likely going to be a training effect from one interface to the other. As such we wanted half of our evaluators to begin on mobile and the other half to begin on desktop which led us to increase the number of evaluators to six.

5.5.2.1 Counteracting Training Effects and Respondent Fatigue

In total there are four possible cross-device UI transition that our system allows. These are from mobile-to-desktop *share view* and *continue on other device* and the same for desktop-to-mobile. In order to reliably test how well these are implemented, we needed to counteract training effects for all four UIs i.e. each transition need to be the first an evaluator did, at least one time. At the same time we have two different designs, conventional and non-conventional. The six respondents were therefore divided into two equally large groups. One group tested desktop-to-mobile, conventional and unconventional and the other tested mobile-to-desktop, conventional and unconventional. This ultimately means that each evaluator tests four UI transitions, either on desktop-to-mobile or mobile-to-desktop. This allows us to compare the usability between the two. Despite only three testers per UI transition, all users complete tasks in both interfaces. As such we maintain six users per interface.
Each UI transition is represented by a task which the evaluator is to complete and will be evaluated using the CPUS and STS survey questions. As such, each evaluator will answer the same questions four times. All surveys run the risk of respondent fatigue [28], making our surveys even more likely to induce this effect on respondents. In order to mitigate respondent fatigue, the order in which the questions were presented were also randomized across all participants for all tasks. See Figure 5.15 for a more detailed explanation.
There is something to be said about comparable groups and random assignment. It is common in experimental research to randomize the groups which are to be compared and avoid systematic differences e.g. age (if not one of the independent variables). Because we have two groups, mobile-to-desktop and desktop-to-mobile we ran the risk of introducing this systematic difference. Six evaluators were contacted simultaneously, asking for their participation in the evaluations. Out of these, five responded. The would be sixth evaluator was contacted at a later stage. These were then put in one of six possible slots on a first come first serve basis i.e. the first person to provide a positive answer about their participation got the first slot and so on. Because we could not predict which participant would answer first, this method of recruiting is akin to random assignment in that we could not affect nor know the order of the participants until they are already placed in a slot.

5.5.2.2 The Scenarios

As mentioned above, in order to test UI transitions, we needed to create scenarios for which the use would need to complete a series of tasks. In order to be able

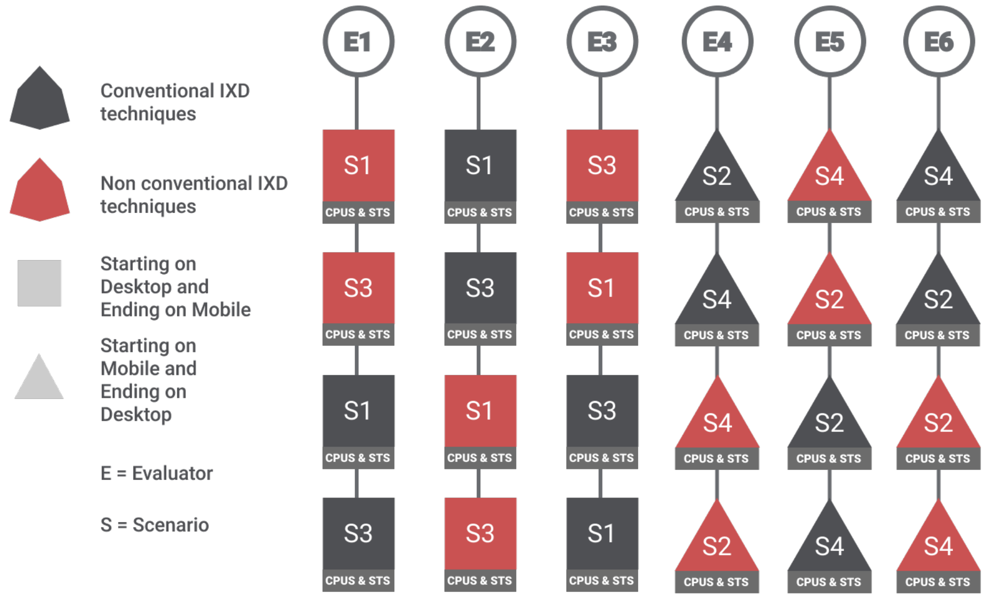

Figure 5.15: Overview of the the order in which each evaluator was presented with the scenarios and combinations of conventional and non-conventional device transitions.

compare results within groups (mobile-to-desktop and desktop-to-mobile) between conventional and non-conventional designs, we decided that the scenarios and tasks for those should be the same. This resulted in two scenarios being created for each group. Table 5.3 and 5.4 show these in detail.

5.5.3 Briefing

Evaluators were recruited from a convenience sample. Because the project is in development and no similar products exists, showing parts of the products, i.e. the part we are designing, to potential clients was not an option. Because of this evaluators were recruited from personnel at Sweco. A total of six evaluators participated in the evaluations. Out of these, two were female and four were men. Out of these four had the role of BIM-Coordinator with day to day tasks including creating and manipulating spaces. The last two were one project manager and one project leader with daily contact with clients who use the BIM models. Both Mobile-to-desktop and Desktop-to-mobile were evaluated by one female and two men. Before the evaluation began, evaluators were briefed regarding the purpose of the evaluation as well as how the evaluation would be conducted. First they were presented with a consent form, informing them about what kind of data would be recorded and that the data would be handled in accordance with The General Data Protection Regulation (GDPR). The data recorded was: Their answers to the survey questions, the position of their clicks in the prototypes, their voice and screen share. Consent was given by continuing the evaluation after having read the consent form. All evaluators were reminded that partaking in the evaluation is voluntary and that they can choose to end their participation whenever, without motivation. The consent form is further detailed in Appendix C. No compensation was offered for participating in

	Scenarios (S) and tasks (T) for Continue on other device	
	Desktop-to-mobile (S1)	**Mobile-to-desktop (S2)**
	You are at the office creating room spaces. As the system has calculated a geometry for the current room space, you notice that something is off. The geometry doesn't match the model. You want to visit the actual room you are working with and get the real measurements. By continuing your work on your smartphone you can commit the changes on site.	You are talking with a colleague and you decide that you need to create a new LOA with room spaces. As you start creating the first room space, your phone warns you about low battery level. You need to save your progress but realize that you can send your progress to your desktop and continue from there.
T1	Begin by creating a new space on floor 4.	Begin by creating a new space on floor 4.
T2	The found geometry is off. You want to check the actual measurements in the room you're working on. Switch device by finding the appropriate button and continue from there.	Your battery is low and you want to change device without losing your progress. Switch device by finding the appropriate button and continue from there.
T3	You've switched devices and are now on your phone. Add 10 cm to the bottom wall. Then continue until the new room is saved as a new space.	You've switched devices and are now on your desktop. Accept the incoming request by finding the appropriate button and continue. Add 10 cm to the bottom wall. Then continue until the new room is saved as a new space.

Table 5.3: Scenarios and tasks for 'Continue on other device'.

Scenarios (S) and tasks (T) for Share view		
	Desktop-to-mobile (S3)	**Mobile-to-desktop (S4)**
	The manager has asked you to create room spaces for floors 1 through 4. There are many rooms to cover and you've been provided with three interns to help you out. In order to get going quickly, you filter and navigate to the relevant parts of the model on your desktop. You then share that view with the interns.	You're holding a meeting for the managers, one of them asks what a room space is. You device that is easier if you just show them. You filter a floor and enter a room on your mobile. You then share your view with the managers.
T1	Filter the floors so that only floors 1-4 are visible. After you've filtered the floors, uncheck floor 3,2 and 4 (in that order).	Filter the floors so that only floors 1-4 and LOA are visible. Go to Ylva kontor.
T2	Share the view by finding the appropriate button and continue from there.	Share the view by finding the appropriate button and continue from there. Share the view with the three managers.
T3		You've switched devices and are now on your desktop. Accept the incoming request by finding the appropriate button and continue. Add 10 cm to the bottom wall. Then continue until the new room is saved as a new space.

Table 5.4: Scenarios and tasks for 'Share view'.

the evaluations.
After this, evaluators were briefed on what a room-space is, what the tool they are evaluating is and what it is supposed to do and how to carry out think-aloud. Evaluators were then provided with a link to the maze for their evaluation and asked to screen share.
During the evaluation there was one moderator who guided the evaluator through technical challenges such as the prototype not fitting in the screen (solved by changing the zoom of the prototype) and asking them to elaborate on their think-aloud, and one observer who observed the evaluators interaction and took notes.
After the evaluation, evaluators were debriefed. As part of this, they were asked: 1) what parts of the interface they liked, what they didn't like and why, 2) if they had any comments or suggestions, 3) if they understood the purpose of moving between devices in the tasks carried out, and 4) if they could imagine real life use cases for this functionality. The debrief ended with telling the participants about the purpose of the evaluation more in detail as well as allowing evaluators to ask questions about the evaluation.

5.6 Limitations of Maze.design

Prior to selecting maze.design as a usability tool we conducted a faux evaluation to test the limits and capabilities of the tool. During that 'pilot study', we looked at how paths were created, the resulting data with error rates, TTC, heat maps of clicks as well as how to migrate the data. This test proved insufficient in ecological validity as the results from the real evaluation was greatly compromised. The migrated data was put in separate CSV files, for each block (one evaluation contained ca 30 blocks, with a total of 12 evaluations). The CSV files were delimited by commas, but because commas were also used in the context screens and missions, using the commas for structuring the the data in a spreadsheet proved impossible to do without doing it manually. Other results were also distorted, with TTC times reported at up to ten times less than the actual TTC. We also found that as soon as an evaluator went off the expected path for completing a task (including overlays and different states of screens), maze reported this as a failed task, with a misclick rate of one hundred percent while also ceasing to record any screens traversed or the path leading to the end of the mission. This resulted in us having to rely on the videos of recorded screen shares for extracting some of this data, such as TTC. Other data was also extracted manually from the 'results interface' provided by maze.design.

5.7 Eliminated Methods from the Outlined Design Process

During the execution of the design process, adjustments and deviations were made from the original planned execution. These deviations have, been discussed in in this chapter where they occur. Here we detail the methods that weren't carried out at all.

The actual execution of the design process						
Phase	Methods					
Empathize	Litterature Study	Interviews				
Define	Content Analysis	Affinity Diagramming	Find themes	~~How Might We?~~	Feature list	~~Kano analysis~~
Ideate	~~User Stories~~ ~~Brain-storming~~ Body-storming	Sketching				
Prototype	Wireframe					
Evaluate	Usability testing CPUS STS					

Table 5.5: The table of methods that was actually conducted during the Design Process.

User stories [72] were not conducted as planned because their purpose of finding features was already provided because the features were already defined. This rendered "How might we?" [73] questions and the Kano analysis [34, p.106] unnecessary as well. Focus during ideation was directed away from features and instead put towards the ideation of cross-device functionality.
We mentioned brainstorming alongside bodystorming [34, p.20] in the planned execution process. At the time, this was mainly because it wasn't clear at the time how and when there would be carried out. Depending on the resources one or the other could have been more suitable. In reality we conducted bodystorming, which proved sufficient for continuing the design process.

6
Results

We begin this section by presenting the results from the final evaluation and interweave them with the analysis to further the following discussion. Because we have used many different metrics, both quantitative and qualitative, doing it this way allows us to interpret the results in situ as well as combine more than one metric to derive the cause underlying a certain result. It also makes more sense to refer back to a specific interpretation if it is also close to the data it is based on.
We will then close this section by detailing a framework and consolidated guidelines that result from us applying existing research on XDI as we designed the system of interfaces presented in this thesis.

6.1 The Final Evaluation

Here we present the results from the final evaluation. These take the form of quantifiable metrics such as CPUS and STS scores, and Usability Testing as well as the qualitative data from the CTA and the debrief from each evaluation.

6.1.1 CPUS and STS

Table 6.1 shows the independent CPUS scores for all evaluators across all scenarios and UI transitions. The mean score for each evaluator is relatively equal except for evaluator six who produced the maximum score of a hundred for three out of four questionnaires with the fourth not being far off. During the Usability Testing, E6 reported that they would respond distinctly on all questions in the surveys.
This is likely to have had an effect on the results in Table 6.2, under mobile. Looking at the grades for all mobile scenarios, they are uniform to those of desktop. It is reasonable to assume, given the strong answers from evaluator six in Table 6.1 that the mobile scenarios would have produced similar results to that of the desktop scenarios. Under the assumption that the mobile mean is similar to the desktop mean, the mean score for the desktop scenarios is 67.97 or mean grade of C, adjective OK and Marginal respectively for the interpretations. This would suggest that the system of interfaces needs to be improved further.
Interestingly enough, there is relatively little difference between CON and NON-CON designs. This is partly to be expected because of the overlap between the designs. But if either of the designs introduced great problems, this should be represented in the data. This might be the case as seen in Table 6.1 where NON-CON desktop scenarios shows relatively low scores for E1. This suggests that NON-

CPUS scores for all evaluators and means						
	E1	E2	E3	E4	E5	E6
Desktop						
S1 CON	68,75	65,63	75,00			
S3 CON	68,75	71,88	75,00			
S1 NON-CON	59,38	65,63	78,13			
S3 NON-CON	56,25	62,50	68,75			
Mobile						
S2 CON				65,63	71,88	96,88
S4 CON				62,50	68,75	100,00
S2 NON-CON				68,75	65,63	100,00
S4 NON-CON				65,63	62,50	100,00
Evaluator mean	**63,28**	**66,41**	**74,22**	**65,63**	**68,75**	**98,96**

Table 6.1: An overview of CPUS scores for all evaluators. See Appendix E for complete list of extracted data points.

CPUS mean per evaluator and scenario				
Desktop	Grade [60]	Adjective [19], [22]	Acceptable [19], [22]	Score
S1 CON	C	OK	Marginal	69,79
S3 CON	C+	Good	Acceptable	71,88
S1 NON-CON	C	OK	Marginal	67,71
S3 NON-CON	D	OK	Marginal	62,50
Mobile				
S2 CON	B+	Good	Acceptable	78,13
S4 CON	B+	Good	Acceptable	77,08
S2 NON-CON	B+	Good	Acceptable	78,13
S4 NON-CON	B+	Good	Acceptable	76,04
Scenario Mean	**B-**	**Good**	**Acceptable**	**72,66**

Table 6.2: Overview of the CPUS mean per evaluator and scenario, with references to their respective ways of grading interfaces.

Agreement among evaluators on STS questions								
STS 1	E1	E2	E3		E4	E5	E6	%
S1 Con	4	4	4	S2 Con	5	4	5	
S3 Con	4	5	4	S4 Con	4	4	5	
S1 Non-con	4	5	4	S2 Non-Con	5	4	5	
S3 Non-con	3	4	4	S4 Non-Con	4	3	5	
								91%
STS 2								
S1 Con	3	2	3	S2 Con	1	3	1	
S3 Con	3	2	3	S4 Con	1	3	1	
S1 Non-con	2	2	3	S2 Non-Con	1	3	1	
S3 Non-con	2	2	3	S4 Non-Con	2	4	1	
								4%
STS 3								
S1 Con	4	4	4	S2 Con	5	4	5	
S3 Con	4	4	4	S4 Con	4	4	5	
S1 Non-con	4	5	4	S2 Non-Con	5	3	5	
S3 Non-con	4	4	5	S4 Non-Con	4	2	5	
								91%

Table 6.3: Percentage of evaluators that respondend with agree (4) or strongly agree (5) on each STS question. See Appendix E for complete list of extracted data points.

CON desktop needs further investigation. Looking at Figure 5.15 we can see that E1 performed scenarios in NON-CON desktop first. This is true for E3 as well but E3 produced a higher score overall for those scenarios. However, both E1 and E3 produced the individually lowest scores for Desktop NON-CON S3. This suggests that Share view in the NON-CON design suffers from a lack of usability. This does not mitigate that there is likely problems in NON-CON desktop overall, rather it helps pinpoint a possible location where efforts can be targeted.

Table 6.3 shows how each evaluator responded to the STS questions for each Scenario along with the rate of agreement. Agreement is calculated as the percent of answers, for each question, which received either agree or strongly agree on the five point likert scale. This means that a high percentage equals high agreement among the evaluators toward that statement. The second STS statement (STS 2) is negatively phrased “I found I needed to remember information from the user interface on [device A] to be able to continue the horizontal task using the interface on [device B]”. Thus a low score for that statement is a positive result.

Looking at the results then show a high degree of agreement for all three of the STS questions. This would indicate that there is a sufficient amount of continuity between the interfaces, in all UI transitions. It should be noted however that this might be in part due to the fact that evaluators didn’t really change devices, they were simply presented with the mobile interface on the same screen.

Time to completion in seconds						
	E1	E2	E3	E4	E5	E6
First Share	152	85	139	NIL	74	77
Second share	81	35	47	51	62	34
Difference	71	50	92	NIL	12	43
First Continue	251	162	211	96	103	282
Second Continue	67	161	96	46	53	73
Difference	184	1	115	50	50	209

Table 6.4: Mission completion times in seconds for all evaluators.

6.1.2 Time to Completion

Time to completion (TTC) can be used as a measure of efficiency as well as be indicative of learnability. In the former case, it is hard to interpret the results in terms of efficiency because there is no reference to compare them with. This measure becomes more meaningful when a set of evaluations have been completed on consecutive iterations where they can be analysed relative to each other. In other words, we could have seen if the TTC increased or decreased with every iteration. It is unlikely that an external reference of preferable TTC in relation to efficiency would contribute here. To say that: task x should take y time, needs to be situated in the context of the task being carried out. The answer could depend on questions like: is the task long, complex, is the user an expert, why is the task being carried out etc. Once such context dependent reference could be extracted by asking a question similar to the first STS question: "I am satisfied with the amount of time it took to resume the interpreted task from [device A]". By asking users if they felt a task could be completed within a reasonable time and comparing these answers with the actual TTC, we will eventually find a sufficient TTC goal. This is not the only way to achieve this goal. For instance, it is not unlikely that evaluators will report that tasks take to long in usability testing, thus insights regarding preferable TTC times can be gained from observation or other complementary methods such as CTA or debrief interviews.

As a measure of initial learnability, by observing the difference in TTC between the first and second time users performed a task. If the system has good learnability, then one would expect the TTC to drop between the first and the second time. Looking at Table 6.4, we can see that there was a decrease in TTC for all participants over all tasks, between the first and second time they performed that task. Again it is hard to interpret the amount of learnability without a reference. Then again perhaps it is not meaningful to say that x has y better learnability than z, as long as there is sufficient learnability in the system. Instead the TTC can be used to find areas with low or no learnability, such as the task *Continue on other device* for E2. Here the difference is negligible and so something must have prevented E2 from learning how to complete the task. Note that no difference could be calculated for E4 *share view* task because the TTC was not recorded for the first performance of

the task.
Looking at the transcribed video recordings (see Appendix D) we can see that E2 did not perceive that they placed the marker for finding a new geometry the first time they performed the task. It is likely that this affected E2's understanding of the system. Following the guideline of Error Tolerance, Table 6.9, the user should have been made aware that the marker was placed, despite doing so unintentionally. A possible solution then, would be to improve the feedback from the system when users places markers.

6.1.3 Content Analysis on Transcribed Video Recordings from Usability Testing

Content analysis using holistic coding [23], [34, p.40] was used to analyse the qualitative data from the video recorded evaluations. This resulted in a range of problems and other interesting findings reported below.

6.1.3.1 Usability Report

Usability reports are informed by empirical evidence and their goal is to clearly outline problems by reporting negative findings and things that will be fixed. These reports also include positive findings [34]. In our case, this meant going through the transcribed recordings of the usability testing and CTA, including debriefing sessions, to identify these problems and positive findings and their frequencies, categorised by task. This report enables designers to more clearly get an overview of the problems and expressed attitudes during evaluations. The findings will be presented in a structure inspired by the usability report described by Hanington and Martin [34, p.192]. This includes reporting and discussing frequencies of findings as well as the impact and persistence of usability problems.

Reported negative findings and problems found
The most frequent problems identified, with eight occurrences, relates to the transition between devices in share view and the button through which this was performed; the 'Devices button' (see Table 6.5 for all negative findings). Users reported ambiguity regarding this button and some users were looking for a share icon commonly found in other interfaces. These users reported that this button did not relate with their understanding of sharing a view. This is considered to have had great impact on the usability, since not finding buttons and not being able to complete the given task influences the efficiency, effectiveness and satisfaction of a platform. Another instance of clicking the wrong button (displaying square meters, with a frequency of one) was reported when performing the same task, something that also highlights a missing connection between the button and the goal of the task. This problem was however not persistent throughout the evaluation since by the second time evaluators performed the task, they were observed to have learned how to share the view indicating that the operations for share view consist of good idioms. This would also suggest a presence of learnability regarding the composition of the interfaces [54].

Negative Findings and Problems found	
Problem description	**Frequency**
User can't find the action to share the view (does not relate share view with the 'devices button')	4
User reports bad mapping between the 'devices button' icon and the functionality it represents (both mobile and desktop).	4
User presses 'add to existing' instead of 'save as new space' on mobile (hard to discern the difference).	3
User can't find the next action relating to changing the geometry (on desktop)	2
User did not perceive that they moved from mobile to desktop or mobile to desktop (poor feedback).	2
Reported that adjusting the geometry was not as intuitive as the rest of the interface.	2
Observed semantic inconsistencies in the interface. Wrong text on button when sharing and continuing on other device in desktop.	2
User did not perceive that the marker was placed for creating a new space.	1
Reported uncertainty regarding whether a new space was created (poor feedback).	1
User presses the 'M2 button' to reach the CDHP. Can't find the action to continue on other device.	1
Showed uncertainty regarding how 'find new room space' relates to the goal (creating a new space).	1
Reported frustration about inconsistencies between mobile and desktop. "-Did not mirror each other"	1
User reported that they did not understand the barcodes in mobile to desktop (poor recognition).	1
Observation: user described described the action of continuing on other device as "lifting over" the progress to another device.	1

Table 6.5: A list of the negative findings and Problems found. See Appendix D for complete list of extracted data points.

The second most frequent problem (three occurrences) regards users pressing the wrong button out of two in a specific screen. The task instructions stated that the user should save the space as a new space, still we identified three instances of users pressing the 'add to existing' button rather than the 'Save as new space' button. This was, reportedly, because of the difficulties concerned with distinguishing the two and not exactly remembering the instructions for the task. When informed of the instructions, either from evaluation moderators or by checking instructions again, all evaluators completed the mission indicating a low impact and persistence (see Figure 6.1) for a closer look at the buttons. If the evaluator had constructed the task or possessed the task as their own, this may have not been the case.
Poor feedback was reported four times. Evaluators did not perceive the transition

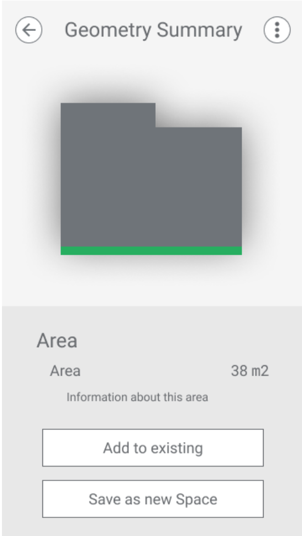

Figure 6.1: The screen providing the option for saving a meta space as new space, or adding it to an existing meta space or space container.

from one device to another, regardless of direction, on two occasions. This reporting was surprising because of the distinct change of UI size and composition. The impact of this finding should be considered low due to the peculiar nature of the evaluation, but at the same time it highlights the already identified problem of evaluating a mobile UI on a desktop platform. It could be the case that evaluators did not recognize or expect this. In a different evaluation setting without the presence of the corona pandemic, forcing us to evaluate remotely, the findings may have varied. Other feedback related issues included evaluators not perceiving the action of placing out markers and realizing that a space had been created, with one occurrence each. One evaluator reported that this could be idiomatic in nature since they had no problem the second time the action was carried out.

Three instances of problems concerned with the combination of desktop and mobile interfaces were identified. Firstly one user: *Reported frustration about inconsistencies between mobile and desktop* with the accompanying quote -"Did not mirror each other" express the opinion that the system has poor recognition. This could be a result of evaluators' expressing the lack of perceptual or semantic consistency and should be considered as highly impactful and a persistent usability problem. Secondly, a more specific usability problem was identified. The barcodes in S1 NON-CON and S3 NON-CON were not perceived as barcodes. Although easy to adjust, this is persistent across the interface and should be considered as a impactful usability problem. Thirdly, an even more specific instance of an interface problem to be fixed is the misspelled text on the button for traversing between platforms in two scenarios, the text spelled 'Share' when it was supposed to have been 'Continue'. This text appears to have had no impact on the evaluators or the result and was observed by the authors.

Reports on positive findings

In the positive findings, what stands out is the degree of which evaluators reported something that could be interpreted as learnability. This was in relation to using UI

Positive findings	
During evaluations	**Frequency**
Task completed without errors and observer notes e.g. Filter the floors or create a new space.	18
Reported learnability in the interfaces e.g. "-Now I've learnt that incoming requests can be found here"	9
User validates the implemented cross-device functionality e.g reports that there is a need.	6
Observed learnability in the interfaces e.g. "-...and then I click this button.."	4
User reports that the interfaces are consistent.	4
User reported that they liked the look and feel of the interfaces	2
User reported that the interfaces as a whole felt intuitive.	2
User reported that the filter function felt intuitive.	1
User reported that they know of no other software that provide the same cross-device functionality.	1
User reported that shaking device followed by a question confirming that action was a good idea. Suggested this is a matter of data integrity.	1
User reported that the interfaces felt down to earth and pragmatic. That it is easy to consume information.	1

Table 6.6: A list of the positive findings. See Appendix D for complete list of extracted data points.

elements a second time during all other than the first task.This was reported a total of thirteen times, and was usually reported in a variation of "I know this [feature] now" referring to a feature that they'd previously explored and now possessed the knowledge to carry out or where to find. Regarding consistency, six occurrences of users liking the look and feel (perceptual consistency), and three occurrences were reported where the evaluator expressed that the interface felt intuitive. Intuitive is a complex expression most closely related to transparency, a key factor of continuity [54]. This can also to some degree be linked to a combination of continuity and consistency.

Other interesting observations include the validation of the platform as a whole. A total of six occurrences reported the need for the tool and that the tool would fill a void because of its uniqueness.

Miscellaneous findings

Other findings include suggestions, neutral observations and observed prototype limitations. All suggestions for XDI techniques and element replacement were recorded and are reported in Table 6.7. These include interesting possibilities such as combining conventional and nonconventional interaction techniques (three occurrences). Given the design of our interfaces it would have been possible to include and combine all interaction techniques for both scenarios into one interactive prototype. During evaluation, this would however have been counterproductive. In our case the sugges-

Other findings	
Suggestions	**Frequency**
Suggests a combination of CON and NON-CON XDI techniques	3
Suggests the sync icon to replace the ‘devices button’ icon (two bent arrows in a circle)	1
Suggests the share icon to replace the ‘devices button’ icon (three dots connected by two diagonal lines)	1
User reports that they think the desktop-to-mobile direction will become less relevant.	1
User reports that filtering on floors is inherently flawed because it shapes information after the visualization need. Cut-level is widely accepted when interaction with Industry Foundation Classes (IFC) file format.	1
Suggests using voice assistants as an interaction technique.	1
User said “Ok, if I don’t choose anybody else, then it is only myself”. This was in regard to continuing on other device. This is a matter of data integrity	1
Miscellaneous	
Observed problems due to prototype limitations	23
Neutral observations neither positive nor negative	18

Table 6.7: A list of other findings discovered during CTA. See Appendix D for complete list of extracted data points.

tion of combining all XDI techniques can be viewed as a indirect positive statement. Another interaction technique brought up during evaluation is navigating and performing actions through the use of voice assistants, something discussed in greater detail in Section 7.

Prototype limitations, with twenty three occurrences, include dead ends in the wireframe in which evaluators had to navigate back to the previous screen or when non-interactive parts of the prototype were clicked or tapped. In these cases evaluators were told that if something was not responding, it probably isn’t clickable (see Figure 6.2).

Figure 6.2: Heatmap showing where in prototype the evaluator clicked.

6.2 Cross-Device Functionality Dimensions Framework

Brudy et al. [63] provided six Key Characteristics or Dimensions of the cross-device design space (mentioned in detail in Section 2). These can then be used to look at existing research or inform new endeavors. During the design process we adopted and adapted this taxonomy to help us look at cross-device design at a functional level. By filling in how a specific cross-device functionality relates to each dimension, as seen in Table 6.8, we can describe a function in terms of specific properties. This framework allows us to make conscious design decisions or simply explore the cross-device design space in a systematic way. Table 6.8 shows the *continue on other device* functionality for conventional interaction techniques. Here it stands as an example of how the framework can be used. On the temporal dimension, the function is described as asynchronous. As explained in Section 5, *continue on other device* moves the progress from one device to another. No two devices can have the same progress, as such interaction is consecutive and by definition asynchronous. This affects the configuration dimension where function necessarily falls under migratory i.e the progress has been migrated to another device. Had the progress been synchronized across two or more devices, other than the obvious switch to synchronized in the temporal dimension, the functionality would be categorized under the distributed property.

The *continue on other device* function is described as one user many devices. Or many users with one device each. In this case the limit would be two users with one device each since only one device can hold the progress at any one time. On the scale dimension *continue on other device* covers all properties. This is because the conventional interaction technique does not make any claims on the distance between devices. This relates to the Space dimensions where it is defined as remote, because there is no demand on co-location (even if co-location is still possible). If we look at *continue on other device* NON-CON we use barcodes and shaking. Both of these have proximity demands and as such *continue on other device* NON-CON would be described as co-located. Dynamics regard the mobility of devices and reconfigurability of connections. While some devices such as stationary workstations are fixed to a certain space. In the designed functionality here, users have full control over which devices are part of a cross-device interaction, as such the dynamics dimension is described as ad-hoc.

During our analysis of non-con interaction techniques, we noticed that many of them depended on what we have described as continuous connectivity, i.e. the connection is made and then persists for some time. This is not the case in our design, and while Brudy et al. [63] points out that connections can terminate themselves after some cross-device action, they don't provide this as a dimension. This is not a fault in their study but rather a difference of scope as they aim at defining research made on the XDI design space, not functionality per se. Still we found it useful to talk about connectivity and so we added it as a new dimension. Previously when we have talked about connectivity we have mentioned two forms. Either non-continuous i.e. the connection is made and then terminated as soon as the task has been completed,

Continue on other device (CON)						
Dimensions						
Temporal [63]	***Synchronous***			***Asynchronous***		
Configuration [63]	*Mirrored*	*Distributed*		*Migratory*		
		Spatial Distribution	*Logical Distribution Second Screen*			
Relationship [63]	1...m	1...1 X 1...1	n...m			
Scale [63]	Near	Personal	Social	Public		
Dynamics [63]	AD-hoc	Semi-fixed	Fixed			
Space [63]	Co-located	Remote				
Cross-device Connectivity	Continuous Persistent	Continuous Session	Sporadic			
Collaboration	Collaborative	Non-collaborative				
Distribution Of Functionality [27]	Symmetrical	Asymmetrical				
Component Role Allocation [27]	Task-based	Situation-Based				
Transition Direction	Desktop-> Small Device	Small Device -> Desktop	Both			
Configuration Phase [63]	On Screen	Around Device	Device Motion	Changing Shape of Device	Body Gestures	None
Content Engagement Phase [63]	On Screen	Around Device	Device Motion	Changing Shape of Device	Body Gestures	None
Disengagement Phase [63]	On Screen	Around Device	Device Motion	Changing Shape of Device	Body Gestures	None

Table 6.8: The Cross-Device Functionality Dimensions Framework, mapped to the scenario 'Continue on other device'.

or continuous i.e. the connection is made and kept alive until disengagement. There is nothing to say that there is a time-limit on the connection, despite many interaction techniques depending on tracking devices or users where connection might be terminated if the device or user leaves. It is possible then that connectivity can be continuous on a scale from a few moments to, theoretically, infinity. Practically it is probably more useful to talk in terms of minutes or hours versus days or weeks. We suggest then three forms of connectivity: Sporadic, where connections are made when needed and terminated instantly when the task is completed. Continuous session, connections are made once before work start and kept alive during a session of work. Continuous persistent, connections are made once and kept alive across sessions. It should be noted that connectivity does not exist in a vacuum. If we look at it in our framework, the dimension scale could interact with *connectivity*. An example would be a tabletop with an active area which tracks devices. In all likelihood this would be labeled Continuous session, but if the devices never left the active area the connection would be identical to Continuous persistent.

We also added a collaboration dimension. While collaboration is part of the relationship dimension in Brudy et al. [63], we target a specific meaning. While XDI generally affords collaboration, XDI functionality does not necessarily need to be collaborative. Point in case, when users *continue on other device* the progress is migrated between two devices. The progress cannot be manipulated by more than one device at a time and so the function is not collaborative. Say that the progress was instead synchronized between two devices where two users could simultaneously manipulate the progress, then that would have been an example of a collaborative functionality, in our sense.

Functional symmetry regards how functions are spread out across devices. Symmetry meaning that all functions exist on all devices. Wäljas et al. [27] promote functional symmetry but there are cases where it isn't suitable. Because there is a choice to be made, we added functional symmetry to our framework. Component role allocation is directly related to functional symmetry. Wäljas et al. [27] state that distribution of functionality can be either 1) task-based - functions are distributed across devices based on what task that device should be used for. Or 2) situation-based - where functionality is symmetrical and you choose a device that suits the situation e.g. in the office or on the road.

When designing for the NON-CON interaction techniques, we noted that because of the difference in affordances between devices. Some interaction techniques can only be used on certain devices. An example would be shaking which can only be done on mobile devices (in the context of this thesis). This makes it meaningful to talk about the direction of the cross-device functionality, is it bound to a certain direction or is it available for all devices. Note that within this framework we only provide the directions we established. For other projects these directions should be extended or revised.

Finally we added the phases of cross-device interaction provided by Brudy et al. [63] as dimensions to the framework. The properties of these dimensions represent the input modalities for the interaction techniques used for that phase. Together they also make explicit how the connection and interaction is set up in terms of input modalities.

6.3 Consolidated Guidelines

During our literature study we noticed an overlap in the recommendations and guidelines provided on XDI. This is not surprising, it probably indicates that they are good and useful. Still, they do vary a bit in how they are presented and what they say. To better make use of the guidelines and recommendations we found, we consolidated these such that overlapping recommendations were merged into one. During this consolidation we used our experiences from the design process in an attempt at enhancing them further. As such the titles in Table 6.9 provide references to the original guidelines and recommendations and the guidelines show our colored interpretations of those titles. Providing the guidelines with titles also enables us to quickly refer to one specific guideline, rather than describing which one is meant in discussion. One emergent feature in the guidelines is that some of them are somewhat general in the sense that not all of them directly relate to XDI but rather design in general. This is not surprising as designing for XDI is a subset of designing for interaction in general.

The consolidated guidelines are divided into four headings, Composition, Continuity, Consistency and Accessibility guidelines. The first three headings are derived from Wäljas et al. [27] three C's, mentioned in Section 2.3. Under these headings we have gathered recommendations that affect these characteristics of a cross-device interface. For example, the Composition of a system of interfaces should afford symmetric functionality, according to the guideline Functional symmetry. However, designers can deviate from adhering functional symmetry if the component role allocation is task-based. Another motivation for deviating from the functional symmetry guideline is Compositional trade-off. Here it is stated that designers may remove functions (thus breaking the functional symmetry) if the value of doing so is sufficiently large.

Continuity contain recommendations that target the transition between devices. For example, the guideline Cross-platform transitions state that a system of interfaces must tell the user how they can actually move from one device to another. Task migration and synchronisation of actions and content instead refers to that data should be kept the same between devices. Thus the act of storing and synchronising data needs to be considered and planned.

The Consistency section mainly refers to how a user perceives the components that make up the cross-device interfaces. Functional consistency refers to the interactivity between devices and states that these should aim at behaving the same even if the look and feel is different. Perceptual, semantic and syntactic consistency states that it is preferable that these to the highest degree are as similar as possible when interacting with different devices. Learnability, Recognition and Transparency provides recommendations in line with more traditional UX recommendations and what to design for when a user is interacting with different interfaces of the same system on different devices, such as letting users know of existing functions, only having to learn idioms once and recognizing elements across interfaces.

The final heading, Accessibility guidelines, is more general in its nature as it describes how interfaces should behave to best adhere to people with requirements or disabilities, while also touching on topics such as system response. It should be

noted that the guidelines are not written as to be in conflict or mutually exclusive to one another. A designer can still strive for functional symmetry while also implementing task-based functionality in one device. Rather these guidelines provide a means of making informed decisions.
These guidelines should be considered separate from the framework in the previous section, since they can be used in absence of each other. While the framework allows for ideation and mapping of functions, the guidelines instead provides guidance on how features should be designed and behave across devices. Despite this, there's nothing that hinders the designer from using these in combination with each other, by first describing existing or novel features using the framework and then deciding on how these should behave using the guidelines.

Consolidated guidelines from the SOA and RTD

Title	Guideline
Composition	
Functional symmetry [11]	Composition should afford symmetric functionality.
Component role allocation [27]	Component Role allocation and distribution of functionality needs to be in line with each other. In other words, if role allocation is task-based, then distribution of functionality should to be asymmetric.
Compositional trade-off [11]	If the value of being able to use a system in mobile contexts is sufficiently large, it is acceptable to remove less important features that are present in more advanced platforms (which are not mobile).
Functional modularity [27]	Devices should be able to adapt to different situations, even in highly specialized systems.
Interaction context	When choosing interaction techniques, it is important to consider the context in which this will be used. The designer should consider adding another interaction technique for achieving the same goal if there are contexts in which the first technique cannot be used. (See Section 7.3.7)
Continuity	
Cross-platform transitions [27]	The interface should provide sufficient information such that the user can transition from one device to another. It is not enough that the user knows that the devices are connected.
Task migration and Synchronisation of actions and content [27]	Content and actions should be synchronized across all devices. For example, database changes should be simultaneous.
Consistency	

Continued on next page

Table 6.9 – continued from previous page

Title	Guideline
Functional consistency [27]	If two or more devices share the same level of interactivity, information and services should be the same across all those devices. Even if not all information or services are needed or shown, given the current composition.
Perceptual consistency [11], [27]	It is preferable to design for a similar look and feel across devices.
Semantic consistency [27]	Interfaces should share a common language and phrasing as well a symbols.
Syntactic consistency [27]	Functionality across interfaces should follow the same operations to achieve.
Learnability [54]	If possible, design the interface so that the user only have to learn idioms once.
Recognition [54]	The system should enable users to recognize interface elements across interfaces.
Transparency [54]	The designer should aim for designing interfaces that are clear enough for users to understand available functions.
Accessibility guidelines	
Equitable use [44]	Interfaces should be designed to be useful to people with disabilities. It is preferable that the interface can be used by all without separate configurations.
Flexibility in use [44]	Interfaces should accommodate individual preferences (that better suit their mental models or needs)
Simple and intuitive use [44]	Interfaces should aim at being intuitive, however there can be aspects where they need to be idiomatic.
Perceptible information [44]	Information should be communicated in a way that it is accessible to users regardless of context or disabilities.
Error tolerance [44]	Design should minimize the potential for unintended actions, reduce the cost of committing such actions and allow users to undo actions.

Table 6.9: The consolidated guidelines resulting from reviewing the SOA and conducting RTD.

7

Discussion

Under this topic we will first discuss limitations that affected the study and how these were overcome in some instances. We will then go on to talk about the the final design, what the results meant for coming iterations and what would have been the next steps. After this we will discuss the SOA presented in Theory and try to answer the first part of the research question *'How usable is the state of the art on cross-device interaction when designing in a Building Information Modeling context?'*. We then continue to discuss Research Through Design and answer the second part of the research question *'How can we contribute to the field of cross-device interaction through research through design?'*. Finally we discuss the ethical implications and considerations in our study.

7.1 Limiting the Scope of the Design Project

We have presented many of the deviations from the planned design process as they appear in section 5.1. However, one of the bigger limitations to the scope of the project came out of a workshop with a key stakeholder (see Section 5.2). It was there that we realized that the features of the tool we were designing for were already defined, in an informal way however. However that workshop helped us formalize these features, narrowing the the scope of the project along with it.

7.1.1 Problems of Designing Interactivity in the Prototype

Prototyping interactivity proved to be a time consuming task despite prior knowledge and experience using the software. The use of what Figma call components allowed us to create instances, quickly change their appearance and switch them out through the use of software functionality. Still, to make menus interactable to a sufficient degree, where a user could explore the interface, there was a need for a lot of screens for displaying different states. During prototyping, another Figma tool allowed us to design menus, connect them to a button and have them appear wherever an instance of that button appeared. Things like this helped us save time that otherwise would have been spent redesigning the same things. But this did not change the fact that there were so many cases that still needed separate screens. The screens did not contain placeholder pictures, backgrounds or other usually found elements that significantly enlarge screen file size. Despite this, as mentioned in Section 5.5, the project became considerably large, outgrowing the maze.design size limits. This meant that we had to keep track of two separate projects and their prototype

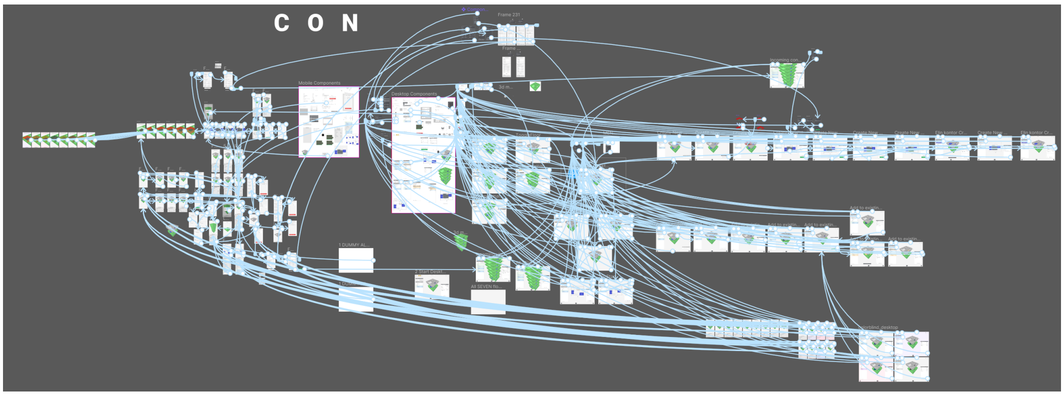

Figure 7.1: An overview of the protoype connections used to transition between screens in Figma, for the CON scenarios.

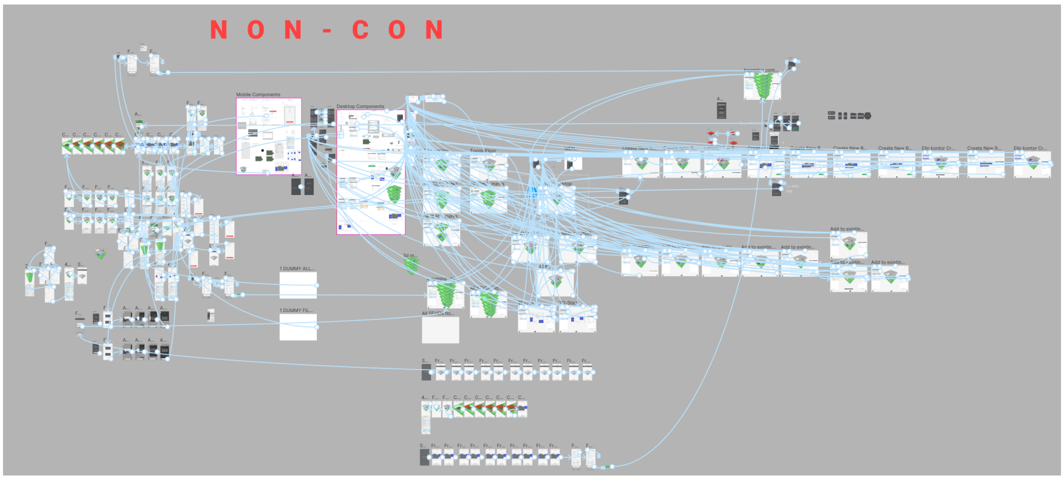

Figure 7.2: An overview of the protoype connections used to transition between screens in Figma, for the NON-CON scenarios.

couplings. The projects CON and NON-CON contained approximately 160 and 110 screens respectively, 77 overlays for menus, approximately 200 components, states, animations, and uncountable wireframe connections. These can be seen in Figures 7.1 and 7.2 as blue lines going from one frame to another, and each of these also carried a separate animation. Because we had to keep both prototypes in the same document, we had to refrain from using a device frame around the screens, something that would have made it more clear to the evaluators what interface and device they were faced with. This is because only one "device" frame can be selected for prototyping at any one time.

The takeaways from constructing the prototype in Figma is that complex software prototyping rapidly becomes hard to manage in terms of manipulation and overview of the interface. Educating the user with system feedback on progress and showing the different states of the program to enable exploration was a huge goal for both the authors and Sweco going into this project. However when this was attempted, the complexity increased significantly. During wireframing, the limitations of prototyping tools such as Figma were revealed. Because the prototype is made out of static screens, wireframing interaction with the 3D viewer was difficult. In this context then, Figma is probably more useful for exploring look and feel rather than interaction.

7.2 The Limitations of the Remote Evaluation

Due to having to conduct the evaluations remotely (because of the corona pandemic), significant deviations from the planned on site evaluations had to be made. Not being collocated prevented us from controlling the environment in which the participants conducted the evaluation. This might have introduced factors that vary between evaluators. Since we had no control over what devices the evaluation was carried out on, the devices may have varied in screen size and color representations which might influence how well different UI elements were distinguished from each other. In a collocated setting this might have been desired since it would let us view the interface through a range of different devices and fix potential problems. However, in this setting it instead posed the threat of being an influencing factor. Other environmental factors might include background noise and other sounds in the vicinity of the evaluator. For instance, one evaluator had a close relative present, practicing an instrument in the background, a factor that was present throughout the whole evaluation.
Since none of the evaluators were told to activate their web camera, we had no chance of recognizing, interpreting or identifying facial expressions as a tool for sparking conversations regarding tasks or missions. Focus was instead put towards spectating their shared screen, something that on the other hand proved easier instead of spectating as a bystander from the side. There were two reasons for deciding to not have evaluators turn on their web cameras. Firstly, it would have been hard to combine with the concurrent screen share, especially if evaluators only have one screen. Secondly, we felt that recording people's live stream from with in their homes could constitute a violation of privacy that wasn't warranted given the value it would have brought our results.
One final limitation of remote evaluation was that evaluators had to evaluate mobile interfaces and the XDI transitions on the same screen using the same input modalities. Having to simulate nonconventional interaction techniques on screen rather than having participants actually interact with the different devices and separating wireframe screens onto those is also problematic. If the evaluations were not held remotely, participants would have had one wireframe for each device, requiring them to physically interact with that device, which would have increased the ecological validity. Not being able to tap in a mobile setting but instead being forced to click using a mouse is something that may affect the validity of the results from interacting with the prototype

7.3 The Cross-Device Interfaces

Here we firstly address the comparison between two designs. We then go on to address the results from the final evaluation and finally summarize these as suggestions for future iterations.

7.3.1 Comparing the Interfaces

The final part of our proposed design process is Compare. Here we were supposed to compare the different designs produced as a result of that process to see which design performed best. Because we deviated from the planned design process, there is only one overall design with different interaction techniques. As such it isn't really meaningful to compare them in that way here. As reported by one of the evaluators, these interaction techniques can be used side by side, which would increase the functional modularity in the system as a whole. We can however identify some differences between the CON and NON-CON interaction technique implementations. The results reveal a difference in usability for one of the conditions, share view on NON-CON desktop, suggesting that this is an area in need of revision. Another observation of interface differences is the fact that when a user receives a shared view or progress, they were in fact different on different devices. On mobile, users saw a modal dialogue window prohibiting them from continuing working and forcing them to make a decision whether to accept or not. On desktop, these took the form of an inbox, where the user could accept at any time. This was motivated, like many other choices, by our own experiences with conventional interfaces and our combined judgement. It is likely that a user performs more time consuming tasks on the desktop spanning longer time periods, therefore we thought it made more sense to not interrupt the user mid task, but rather to allow them to accept incoming requests at any time.The overall score for the system of interfaces across all conditions provided a combined SUS score of 72.66. However these results were most likely skewed and the true score is more likely closer to 67, suggesting that the interface is marginally acceptable and needs revision.

7.3.2 Possible Changes in Relevant UI Transitions

One of the respondents reported that they think that desktop environments will be rendered obsolete in a near future. Furthermore, the same respondent pointed to an already ongoing transition from desktop to mobile devices in parts of the BIM industry. Despite including a desktop interface in our cross-device system, this does not invalidate the design choices made. As mentioned in the Prototype section, we designed for mobile first. We also adhered to the guidelines of functional symmetry and kept the component role allocation situation-based (see Table 6.8). This would soften the blow of a sudden transition from mixed desktop and mobile usage to mobile only. If any, these reportings validate the guideline regarding functional symmetry and the choice to make component role allocation explicit in our framework.

7.3.3 Metaphors and Mental Models

During one of the evaluations, one of the evaluators framed their action as "lifting over to another device". This was in regard to *continue on other device*. This spurred the question of which metaphor better suits the action. While we did think of this as we designed the interfaces, this was a new way of looking at it. Another evaluator suggested a common sync icon to replace the current ‘Device Button’, namely two bent arrows pointing towards each other in a sort of circle. This too is likely to be a reflection of the evaluators mental model of what is going on as well as current convention for similar actions such as synching. When we described the cross-device functionality in the section Connecting the Interfaces (5.4.6), we used states and the JS object as a data structure for those states to describe what was happening. One possible phrasing of the functions would then be to use state transfer and state share. But it is unclear how intuitive this would have been. Instead we went with *share view* and *continue on other device*. This is based on asking ourselves the question “what is it I am sharing and what is it I am doing when I continue one task on another device?”. The results produced by this did not lie far from the question. The results from the evaluation are mixed in terms of how well the phrasing matches the mental models of the users. On one hand there are three reports of the system and its parts being intuitive. On the other hand, one user explicitly used another mental model to describe their actions. This indicates that this area of the design needs to be explored and evaluated further, preferably by those who will use the interface.

7.3.4 Information Visualization

In Table 6.5, one evaluator reports that filtering on floors is inherently flawed because it shapes information after the visualization need. This is a concern that is likely to be unique to the BIM context. While there surely exists a body of knowledge on information visualization in BIM viewers and 3D modes, it is unknown to us how well explored the BIM viewers and 3D models are in an XDI environment. It should be noted that the evaluators aren’t fully representative of the end user (detailed further in Section 5.1) and that their tasks and needs may vary. We can therefore not recommend any course of action other than seeking to identify the needs and solutions when potential end users become available.

7.3.5 Data Integrity

During the evaluations, one evaluator reported that there is a potential threat to data integrity with some of the cross-device functionality (see Table 6.6). More precisely this was in relation to shaking a smartphone to share the current view. The user was asked if they want to share their view, after having shook their mobile. After this the user has little to no control over who accepts that view. The functionality is intended to be shared with people in a physically close proximity, calculated based on network location. This limits access to people on the same network and to a certain range but the person sharing can’t stop anyone on the same network and in range from taking part of that view. This specific problem is probably easy to solve but it is indicative of a greater, less apparent problem. Different interaction techniques may come with unknown data integrity problems. Both future research and future designs could do well to explore potential data integrity threats which is not necessarily technical in nature.

In light of this, one evaluator voiced “Ok, if I don’t choose anybody else, then it is only myself” (Table 6.7) when selecting a device to continue their progress on. In this case, the evaluator seemed certain that they were only sharing data with themselves. But making sure that this is always the case, i.e. that users know with whom they are sharing information, is something that can be leveraged when trying to maintain data integrity. A well informed user is probably less likely to share information with others than those intended.

7.3.6 Partner Devices

Many of the interaction techniques listed in Brudy et al. [63] suggest smartwatches or other wearables. With the advent of smart wearable devices behind us. Hopefully moving increasingly towards maturity, could these devices be used as an interface, or a sort of hardware middleware? Could a smartwatch that has nothing to do with the spaces app still be used to afford a desktop computer with non-conventional interaction techniques? It is not uncommon that desktops are fitted with web cameras and it’s is extremely common in laptops. Perhaps scanning barcodes should not be considered unidirectional such as we have described earlier in the thesis. Research on cross-device wearables suggest that this idea is not too far off [53] [49]. One might argue that if we can rely on smartwatches why can’t we also use eye tracking, tabletops, kinect sensors and so on. The difference here lies in how readily available the hardware is to users. If we abstract away from any one type of product, the idea still holds. Any device that is readily available to users that afford new input modalities would be suitable as a “partner device”.

7.3.7 Summarizing the Evaluator Feedback and Suggestions for Next Iterations

As with all experiment and evaluation settings, there is most likely an innate portion of artificiality in our evaluations. In other words, the tasks aren’t being executed in the real world with real motivations and goals. During evaluation we observed a couple of instances where users executed the wrong action where we would attribute this to the evaluation being artificial. We put great care into constructing tasks that were as meaningful as possible. Despite this, evaluators had to read the instructions relatively frequently. This highlights an important factor, namely the dissonance that could be derived from evaluators not coming up with the task themselves and therefore not owning the task. This is especially true when there exists no current users from which to extract more organic tasks. It should be noted, however, that evaluators reported that the tasks felt true to the purpose of the tool. In future iterations, end users should be invited to a workshop where organic tasks can be extracted and used in consequent evaluations. This can also prove to be a valuable opportunity for exploring what mental models relates to BIM and the ways in which they are manipulated, since evaluation sparked discussions regarding what different mental models that would be applicable in the BIM setting. Because key components of the BIM setting and its 3D models are iconic in nature, there can be already existing mental models of how to: map out floors, search for rooms and filter data,

that can be leveraged when designing for manipulation of those 3D models. How to visualize information, partner up devices and allow for interaction should therefore be continuously evaluated, as already suggested.
The suggestion of combining CON and NON-CON XDI techniques was brought up during evaluations. This is an interesting suggestion. If there are interaction techniques that can exist in parallel, some users would maybe prefer one over the other, with easier recollection of one of those. If we were to derive something from our results, it would be that providing several independent ways of interacting with interfaces is a good practice. Making such inferences is maybe imperious, but considering them and evaluating the results could provide insights on what best suits the given context the designer aims to design for. If there are situation-based interaction technique contexts that better support interaction 'then and there'; allow for for it. In the case of this specific project, voice assistants is one of the interaction techniques that should be explored further since it is a unique combination of novel and transparent interaction relying on already readily available hardware.
We recommend designers to prototype and wireframe a mobile first approach, in tools and environments that allows for synthetic manipulation of 3D models. Maintaining functional symmetry whenever possible may also be critical to prevent the risks following paradigm changes in device usage. This is in line line with current research [61]. It can prove to be critical that the functional symmetry dimension aligns with component role allocation dimension discussed in our framework, so that component role allocation is situation-based to the highest degree.
Using conventional icons could prove more decisive than introducing new ones, however this needs to put in relation to what it is that the designer is trying to achieve. A share icon might map better to the task of sharing a view, but if the intention is to introduce novel combination of functions, design these with careful attention to learnability and recognition. As Cooper et al. state: “All idioms must be learned; good idioms need to be learned only once” [41, p.309].

7.4 The SOA Versus the BIM Context

Under this topic we will discuss the SOA such as we have described it in theory and put it up against out experiences as we tried to use that theory in designing a system of interfaces for cross-device interaction. This aims at answering the first part of our research questions *'How usable is the state of the art on cross-device interaction when designing in a Building Information Modeling context'*

7.4.1 Spaces

As we set out to design a tool for creating spaces in the beginning of this thesis, we looked to see how we could explain them in other terms than what they are functionally, i.e. geometries with associated data relating to some 3D model of a building. We landed on virtual spaces and argued for why these kind of spaces should also belong to the virtual domain. This with the ambition of using knowledge on working and collaborating in such virtual spaces to try to find and design creative ways of interacting with spaces in BIM. This bore fruit in discussions of how connecting sensors in physical spaces could be mapped to their virtual counterparts, letting the virtual room stand in lieu of the physical room in more ways than geometry. Another potential use case discussed was using virtual spaces to furniture and design rooms, known as projecting, in advance of their physical ilk's erection. We are sure there is great potential in considering these technical spaces as virtual. However, the pursuit would have extended beyond the reach of this thesis. To remain in scope, the part we designed for was reduced to its' core features, leaving the potential of spaces in BIM to future iterations. As such virtual spaces are left virtually unexplored during the design process and consequent sections of this thesis.

7.4.2 Connectivity - The Lack Thereof

Many of the interaction techniques presented in Brudy et al. [63] assume what we chose to call continuous connectivity, where the connection between devices is persistent. This is made evident by the three phases they divide interaction techniques into: configuration, content engagement and disengagement. The last phase implies that there is an ongoing connectivity that needs to be disengaged. Brudy et al. [63] do state, however, that one interaction technique may span more than one phase i.e. dragging a file between two devices can both create a connection and afford content engagement. There is nothing to say that this connection can not also automatically terminate when the content has been moved. This however, is implicit, compared to the explicit structure of the presented interaction techniques. This indicates that a great deal of research has been made on XDI with continuous interaction. It might be the case that the over-representation of continuous connectivity is the result of many years of earlier research done on multi-monitor workstations, multi-device environments and spaces (Areas 1 and 2 in Brudy et al. [63, p.3]) prior to the advent of Ad-Hoc, Mobile Cross-Device Use (Area 3). This however does not change the fact that sporadic connectivity is not explicitly mentioned. The functionality that emerged from our ideation sessions is based on the insights from our empathize phase, this proves the need for more research in to this kind of cross-device interaction.

7.4.3 The Corpus of Interaction Techniques

Another phenomenon that is made evident by our analysis of the interaction techniques provided by Brudy et al. [63] is that the vast majority of interaction techniques rely on comparatively uncommon hardware (compared to smartphones and laptops or desktops) such as kinect, eye-tracking equipment or other means of tracking users or their devices. This is understandable and even motivated. If science does not explore the frontier, then what good is it. But it also reveals a dissonance between academia and industry. It is probably unlikely that Sweco would buy large amounts of kinects in order to ubiquitously serve their personnel with non-conventional interaction techniques such as gestures. This of course begs the question: Does all functionality need to be ubiquitous or could they be set in say meeting rooms? While ubiquity is not necessary, it is probably wanted in many cases. Just the task of informing users when and where they can make use of cross-device functionality which is not ubiquitous, poses a massive information visualization problem in and of itself, not to mention a data integrity problem (see Section 7.3.5)

7.4.4 Unvoiced Voice Assistants

During the evaluator sessions, one evaluator mentioned voice assistants as a possible way of interacting with content. Upon further discussion during the debrief, the use of voice assistants was posed a valid and interesting XDI technique, both for interacting with content but also when completing the tasks in the scenarios. Voice assistants as an interaction technique is not mentioned in Brudy et al. [63]. There is no reason why we shouldn't be able to share our view or continue on other devices using this interaction technique. This gap in research shines some light on the current SOA when 510 reviewed papers does not mention voice assistants at all. Maybe this is an untapped potential of moving between devices, with the technology already ready in our current devices. Instead of relying on external sensors such as RGB camera lamps and depth cameras, we could maybe harvest already built in hardware and enable a possibly intuitive and accessible way of transitioning between devices. Which is the case will be left for future work and research.

7.4.5 Summary

There is no denying that the SOA is indeed usable, anything else would be extraordinary. Table 7.1 detail the key components for a good cross-device user experience. It also highlights different metrics and evaluations that are mentioned in the SOA and how we measured them. Finally we included some of the factors influencing each key characteristic. Our research has found existing areas which the literature does not seem to cover. These include the dimension of connectivity and more specifically XDI that lasts for only short periods of time. The body of interaction techniques found in Brudy et al. [63] were focused on unusual hardware that is likely hard to apply in an enterprise environment. At the same time this body of knowledge does not seem to cover newer ways of interacting with devices such as voice assistants. We recommend that future research look in to these areas to widen the relevance of XDI research even further.

Overview of Metrics and Methods Used in This Project					
Efficiency	Effectiveness	Satisfaction	Composition	Continuity	Consistency
Time to Completion (Task duration) [54]	Task Completion [54]	Cross-platform Usability Scale [54]	Component Role Allocation [27]	Seamless Transition Scale [54]	Usability Testing Using CTA [34]
			Distribution of Functionality [27]		Learnability [27]
			Functional Modularity [27]		Recognition [27]
Metric or Questionnaire Dimension Framework Guideline					Transparancy [27]

Table 7.1: An overview of metrics and methods used in this project.

7.5 Discussing Research Through Design

Here we first discuss our research in terms of the four lenses provided by Zimmerman, Forlizzi and Evenson [18] to evaluate our research contributions. We then go on to talk a bit more about these in detail. We follow this with a discussion on using the PRT as a journaling format and end this section with a discussion on accessibility and ethical considerations.

The first lens for evaluating research contributions is Process, detailing the processes with which design was carried out [18]. This has been done in detail in Section 5 of this thesis. Invention is the second lens which focuses that researchers must come up with subject matter which is new by means of a literature review as well as display how this progress can advance the field. We carried out a literature study and detailed the SOA of XDI in Section 2 of this thesis. We then identified gaps in the current theory which we've then tried to bridge by producing a framework which help designers discuss phenomena that was previously implicit in the literature along with consolidated guidelines. By doing so we have also answered the second part of our research question *'How can we contribute to the field of Cross-Device Interaction through Research Through Design?'*. The third lens is Relevance, putting the burden of mapping out the current and the prefered state as well as communicating the attempts at reaching the prefered state. The mapping is done in Section 1 of this thesis where we pose a context which is seemingly unexplored and how we can contribute to the field of XDI. The final criteria, extensibility, states that the outcome from the method should be usable in future endeavours of research through design. We meet this criteria by means of our proposed framework and consolidated guidelines. There are concrete deliverables resulting from our execution of the method that can be used to identify other points in the XDI design space. It seems then that our engagement in RTD was successful in terms of these lenses.

7.5.1 Discussing Results; The Dimensions framework

The particulars of the framework is explained in Section 6.2. The framework is not 'a catch all' stocktake of all dimensions relevant to cross-device functionality. Rather it aims at helping future designers make explicit choices about some dimensions which have proved useful in discussions and the design process in this thesis. It mainly aims at describing cross-device at a functional level where each cross-device functionality can have its own property set in the framework. But the framework is based on dimensions used to describe the research done in the field of XDI and so it can also be used to describe whole systems of XDI.

7.5.2 Discussing Results; Guidelines

There is an seemingly endless supply of user interface and user experience guidelines stemming from both research and practitioners. Because any cross-device interface is necessarily a subset of user interfaces, it is not strange that the guidelines for designing XDI overlaps with design for regular UI. Where XDI is different, however, is that users are assumed to move between devices, introducing problems that might not occur when designing for interaction on just one kind of device. That there are similarities and differences between single UI and cross-device interfaces is reflected in the guidelines. Some of these could be considered universal, in any case, they are important and useful when aiming at creating usable and useful designs. Again, these guidelines are not all encompassing, but rather a selection of recurring recommendations and best practices that surfaced during our literature review that proved useful as we carried out the design process.

7.5.3 Discussing PRT

For keeping track of our design process we used our own implementation of PRT recreated in Google Docs, detailed in Section 3.4. When we researched different journaling options, we aimed at finding a journaling structure which let us keep insights and decisions in a structured way on a day to day basis. PRT is designed to do this but its focus is on design activities, as made evident that activities are created as so called 'Events'. In our case the journal became a collaborative platform where we would co-write text together, have discussions about design directions, and have summary meetings. This meant that everyday was treated as a design activity, most of them under the topic 'Design Process', 'Literature study' and 'Evaluation'. The event structure such as we implemented it with links, images and locations, times etc. for each activity were often left empty and only seemed to clutter the disposition. Eventually we removed entries for these in the journal completely and reintroduced them when needed. What did work however was the insights and decision headings for each event i.e. day in our case. Each day we would summarize what had been done and put it into the journal, and whenever we made an insight or a design decision, this was put down in the journal as well. We also implemented a combined to-do and backlog, inspired by how kanban cards are used in e.g. Trello [75]. This helped us in keeping track of the activities we performed during the project as well create traceability. We should note that the way we used the PRT format might have been influenced by the affordances provided by implementing it in a text editor, rather than dedicated software. As such we have not used the format as strictly as intended. In the end it probably boils down to individual needs and preferences, the idea of having an activity based journal is a good one. But we wouldn't recommend it as the only journaling medium for an entire design project.

7.6 Accessibility and Ethical Considerations

When designing UIs it is imperative to be, in so far as possible, inclusive of all potential kinds of users. When we designed for accessibility during this project, it was done in relation to the Web Content Accessibility Guidelines (WCAG) developed by the World Wide Web Consortium. Although it is primarily a checklist for web applications and websites, it illuminates key factors when designing for users with disabilities or impairments and their interaction with interfaces [62].

According to National Eye Institute [64], 1 in 12 men (8 percent) and 1 in 200 (0,5 percent) of all women suffer from some form of color vision deficiency (CVD). There is also users that are partially or fully impaired that to some or full degree rely on screen readers for device interaction. The guidelines state that to avoid confusion, designers need to be as clear as possible in phrasing on buttons, actions and links and not solely rely on colors for distinguishing elements or conveying meaning within the prototype [62]. In line with the guidelines, we used indicators and text alongside color for interface interaction, striving for a contrast ratio of 5:1 between text and background or when separating elements in the design. To check for this we used online tools such as WebAIM Contrast Checker [76] to assess the contrast for adhering and maintaining readability on devices. Colblindor's [69] web interface was used to simulate what different kinds of people with CVD would see on their screen. This provided us with a window into how other people might view interfaces and sparked discussions on what worked well and what needed improvement. An excerpt from this can be seen in Figure 7.3 and Figure 7.4 for each interface.

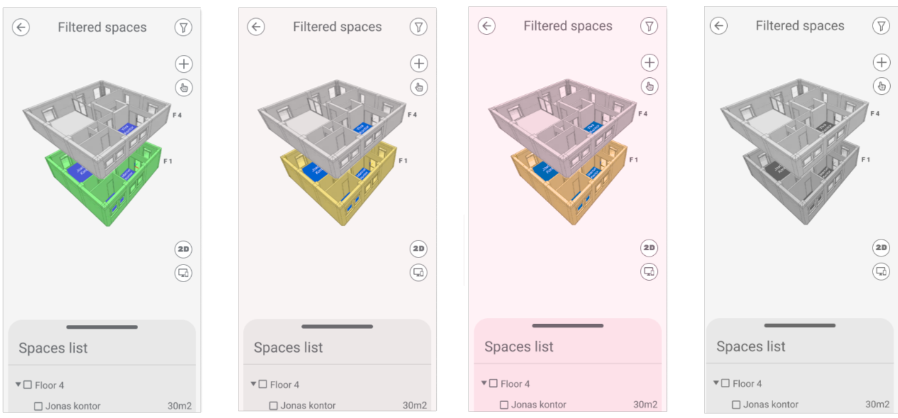

Figure 7.3: Assortment of mobile interface variances, with simulated CVDs. Normal (left), Dichromatic view: Red-Blind/Protanopia (middle left), Dichromatic view: Green-Blind/Deuteranopia (middle right) and Monochromatic view: Monochromacy/Achromatopsia (right).

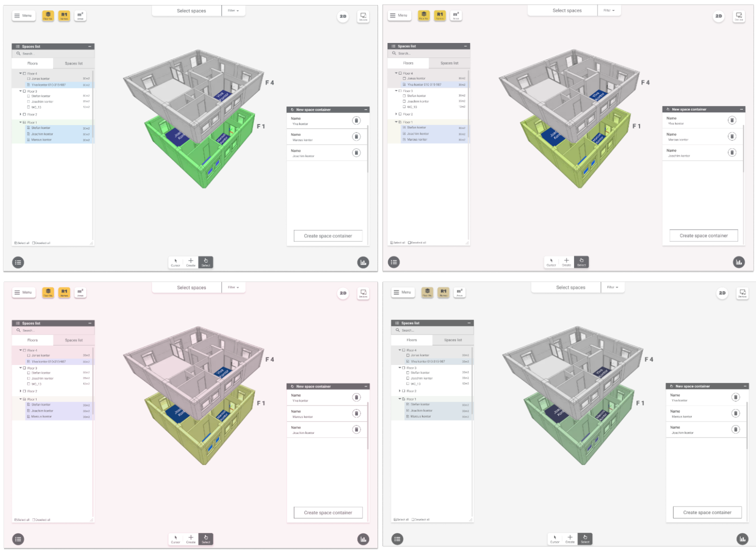

Figure 7.4: Assortment of desktop interface variances, with simulated CVDs. Normal (top left), Anomalous view: Red-Weak/Protanomaly (top right), Dichromatic view: Red-Blind/Protanopia (bottom left) and Monochromatic view: Blue Cone Monochromacy (bottom right).

Other variations in users include hearing impairment, intellectual or cognitive impairments as well as physical impairments. To make software usable for people with these types of impairments, the WCAG suggest allowing for navigating with assistive technologies, avoiding audio and video autoplay to not confuse people with cognitive disabilities. It is also recommended to avoiding flashing content since these can trigger seizures.
None of these were considered an imminent threat to our project or the interface designed, since these consisted of mostly static pictures and some animations for moving screens in and out of the viewport. Physical impairments and screen reader compatibilities were considered outside of the scope as well. Language evaluation was not specifically evaluated but rather as a part of the pilot studies and final evaluation. Although, care was put into describing text on buttons to convey their meaning and what action they were related to. Prior to the execution of the design process, discussions regarding the wording was considered as recommended by WCAG [62]. To make software understandable, the guideline recommends avoiding unusual words, jargon acronyms and abbreviations while also writing content at a 9th grade reading level. We do, however, need to discuss our imminent and obvious departure from this. We would argue that within some contexts, profession specific language, including terms, concepts and abbreviations are unavoidable. The tool created, including our designed prototype, is context specific and will be used in a work environment where the discourse and concepts used in the prototype are of familiarity to users as of practical necessity. It is therefore less relevant to discuss the language of the interface in relation to a general set of guidelines and therefore readability tools were left unused.

8
Conclusions

We have designed a system of interfaces that afford Cross-device interaction based on the SOA on XDI and the results from our iterative design process. The system of interfaces allow users to move and share content between devices in meaningful ways, grounded in the perceived needs of future end users. At this stage the interface suffers from usability issues ranging from poor feedback to conflicting mental models and inconsistencies between the interfaces that affect performance. In contrast to this we also found evidence for learnability in idiomatic operations, reports of a suitable look and feel and that the interface felt intuitive in its composition. The evaluations of this system of interfaces has also produced a series of topics ranging from data integrity concerns and mental models to ways of overcoming the limited affordances in desktop devices. By designing this system of interfaces in order to conduct research through design, we have answered the research question both in regards to 1) *"How usable is the state of the art on Cross-Device Interaction when analysing and designing in a Building Information Modeling context?"* and 2) *"How can we contribute to the field of Cross-Device Interaction through Research Through Design in this context?"*.

In response to RQ1 'how usable the SOA is', we have used the taxonomy provided by Brudy et al. [63]. Their dimensions of XDI design space helped us both anticipate and place our design within that design space. Furthermore we used their list of interaction techniques as a starting point for ideation when we designed for non-conventional interaction techniques. For conventional interaction techniques we drew inspiration from Chong and Gellersen [30] and their list of user-defined actions for connecting devices. As it pertains to evaluation strategies, we did go with what Brudy et al. [63] call demonstration which allowed us to see how well our design fulfills the criteria we extracted during the workshop with a key stakeholder (see Section 5.2.1) as well as perform usability testing. We have used guidelines and recommendations for designing cross-device interaction from Denis and Karsenty [12] and Wäljas et al. [27]. More specifically we have tried to adhere to their notions of composition, continuity and consistency. We also used guidelines and recommendations from Seffah and Javahery [11] and Kuksa et al. [44] where they contribute with what constitutes a good MUI and guidelines for accessibility respectively. Finally, we have used Majrashi's [54] CPUS and STS in order to measure the usability and user experience of cross-device interfaces.

In response to RQ2 'how we might contribute to the field'. Our contributions are fourfold. Firstly, we have identified a gap in the current research on XDI. This gap takes the form of an imbalance in research where interaction techniques for XDI has been heavily dependant on technology which is not readily available in an enterprise context (see Table 5.2). Furthermore, the longevity of the connection between devices has not been made explicit as a dimension of the cross-device design space. The vast majority of interaction techniques seem to be dependant on some sort of continuous connection where as the functionality we have designed relies on what we have chosen to call sporadic connection. This also indicates an underexplored area of XDI research.

Secondly we have produced the beginning of a framework that allow designers to make explicit decisions regarding a set of dimensions defining cross-device functionality. These dimensions are derived both from literature provided by Brudy et al. on the dimensions of the cross-device design space [63], or Wäljas et al. [27] Distribution of Functionality and Component Role allocation as well as our own dimensions. This framework can be used not only to explore new cross-device functionality by shifting the properties in the framework e.g. by means of Lundgren and Gkouskos's [37] skewing method, but also to discuss current functionality in terms of how it is implemented according to these dimensions. This framework aims at, at least partly, bridging the gap in research by providing designers and researchers with a means of explicitly addressing connectivity as one of the dimensions of the design space.

Thirdly, we have collected recommendations and guidelines for designing XDI presented in the literature and created one consolidated set of guidelines. This set of guidelines have also been extended by a few guidelines of our own, stemming from our experiences as we designed for a system of cross-device interfaces. Our hope is that by having easier access to these guidelines in combinations with our extensions, designers can make even better decisions as they design for cross-device interaction.

Lastly, we also provide a practice based contribution through our design. By designing for XDI in a BIM context we have placed a point in the XDI design space. This point both stand to expand the current bounds of this space as well as serve as a take-off point from which other designers can draw inspiration as they move to design for new XDI.

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A

Appendix 1

Målet med intervjun är att få dina förväntningar och erfarenheter. Vi vill veta: vilka uppgifter du har, hur du löser dom idag och vad som fungerar bra och dåligt. Vi vill också få dina åsikter om vad vi kallar meta spaces. Vi kommer att berätta mer om dom sedan.
Inget du säger här är fel eller förolämpande, vi letar efter åsikter och erfarenheter och inte rätt eller fel svar, vi kommer heller inte berätta vidare vad som sagts under intervjun utan detta är ett tillfälle för oss att skaffa oss underlag för vår designprocess. Detta kommer ta ungefär 30 minuter och du får ställa frågor när du vill!
Är det ok för dig om vi spelar in samtalet? Inspelningarna kommer enbart användas för att komplettera våra anteckningar och vi kommer inte dela dom med någon utanför Sweco. Ljudinspelningarna kommer att raderas när projektet är slut, i början av sommaren. Du kan när som helst dra tillbaka ditt samtycke för inspelningen eller intervjun och du behöver inte ange skäl för detta. Om du inte vill att vi använder din data, meddela oss innan intervjun är slut, eftersom datan kommer att anonymiseras under transkriberingen.
Har du några frågor till oss nu?

B

Appendix 2

Follow the URL to see the data from the content analysis. https://bit.ly/2ACPJWE

C
Appendix 3

Vi är studenter från Chalmers Tekniska Högskola som skriver vår masteruppsats för en examen i Interaction Design and Technologies. Vi har i samarbete med Sweco Position AB designat ett system av gränssnitt för att undersöka hur väl den samtida forskningen på Cross-device Interaction (interaktion över flera enheter) relaterar till industri, mer precist företag som jobbar med Building Information Models. Vi behöver din hjälp med att utvärdera detta system av gränssnitt, och om du väljer att fortsätta så kommer du att få genomföra ett antal uppdrag med några uppgifter vardera. Efter varje uppdrag kommer du få svara på några frågor.

För att vi skall kunna tillgodose oss din utvärdering behöver vi samla viss data från dig (som täcks av dataskyddsförordningen, GDPR). Detta kommer att göras i två delar varav den ena är valfri och den andra är obligatorisk för att vi ska kunna genomföra utvärderingen (du kan när som helst välja att avbryta ditt deltagande och du behöver inte motivera varför).

Den första delen (obligatorisk): När du genomför dina uppdrag så kommer dina klick på skärmen att spelas in. Detta görs automatiskt av verktyget och ingen mjukvara behöver installeras för detta. Detta kommer bara ske för interaktionen med gränssnittet och inte utanför prototypen. Dina svar på frågorna efter varje uppdrag kommer också att sparas.

Den andra delen (frivillig): Vi kommer att be dig dela din skärm under utvärderingen. Detta för att låta oss direkt observera hur du interagerar med gränssnittet. Vi har möjlighet att spela in din skärmdelning samt vårt röstsamtal. Denna inspelning kommer främst att användas för att komplettera våra anteckningar, för att säkerställa att vi inte missar något från din feedback från utvärderingen.

Din data kommer hanteras anonymt. Vi kommer inte att dela inspelningarna med tredje part och vi kommer att förstöra filerna senast efter uppsatsens slut, uppskattad till 15 juni, 2020. Resultaten från utvärderingen kommer att presenteras i vår uppsats, under opponering av uppsatsen samt möjligtvis internt på sweco.

Personuppgiftsansvarig är Joachim Pihlgren (joapih@student.chalmers.se) och Marcus Larsson (marcusla@student.chalmers.se). Vill du begära ut information, ta del av de uppgifter vi sparat eller att vi raderar din data, är du välkommen att kontakta oss. Det samma gäller om du vill ta del av resultaten, uppsatsen som resultaten nämns i eller har frågor i övrigt om projektet.

Genom att påbörja utvärderingen samtycker du till att vi samlar din data enligt ovan. Kom ihåg att du när som helst kan avbryta ditt deltagande och/eller återta ditt samtycke, utan att motivera varför.

D

Appendix 4

Follow URL to find the transcribed data https://bit.ly/36XLG3e

E
Appendix 5

In this appendix you will see what Majrashi calls questionnaire responses pre- and post transformation [54]. The pre transformation score (the actual likert scale position) is outlined under each evaluator in grey, and the post transformation is outlined in light blue [58] [54]. Finally you can see the CPUS score for each evaluator and scenario in the yellow cells.

S1 CON (Continue)						**S2 CON (Continue)**					
CPUS											
E1		**E2**		**E3**		**E4**		**E5**		**E6**	
4	3	3	2	4	3	3	2	4	3	5	4
2	3	2	3	3	2	3	2	2	3	1	4
4	3	4	3	5	4	4	3	4	3	5	4
3	2	3	2	3	2	2	3	2	3	1	4
4	3	4	3	4	3	2	1	3	2	4	3
3	2	3	2	2	3	2	3	2	3	1	4
4	3	4	3	4	3	4	3	4	3	5	4
2	3	2	3	1	4	1	4	2	3	1	4
	55		52,5		60		52,5		57,5		77,5
STS											
4		4		4		5		4		5	
3		2		3		1		3		1	
4		4		4		5		4		5	
S3 CON (Filter floors)						**S4 CON (filter floors)**					
CPUS											
E1		**E2**		**E3**		**E4**		**E5**		**E6**	
4	3	4	3	4	3	4	3	3	2	5	4
2	3	2	3	3	2	3	2	2	3	1	4
4	3	4	3	4	3	4	3	4	3	5	4
3	2	2	3	3	2	2	3	2	3	1	4
4	3	3	2	4	3	3	2	3	2	5	4
3	2	2	3	2	3	3	2	2	3	1	4
4	3	3	2	5	4	4	3	4	3	5	4
2	3	1	4	1	4	3	2	2	3	1	4
	55		57,5		60		50		55		80
STS											
4		5		4		4		4		5	
3		2		3		1		3		1	
4		4		4		4		4		5	

Table E.1: Raw data (left column) and post transformation data (right column) for each evaluator's answers to the CPUS and STS questions on desktop.

S1 NON-CON (Continue) / S2 NON-CON (Continue)											
CPUS											
E1		**E2**		**E3**		**E4**		**E5**		**E6**	
3	2	4	3	4	3	3	2	3	2	5	4
2	3	2	3	2	3	3	2	2	3	1	4
3	2	4	3	4	3	4	3	4	3	5	4
3	2	2	3	3	2	2	3	2	3	1	4
4	3	3	2	4	3	4	3	2	1	5	4
3	2	4	1	2	3	3	2	2	3	1	4
3	2	4	3	5	4	4	3	4	3	5	4
2	3	2	3	1	4	1	4	2	3	1	4
	47,5		52,5		62,5		55		52,5		80
STS											
4		5		4		5		4		5	
2		2		3		1		3		1	
4		5		4		5		3		5	

S3 NON-CON (Filter the floors) / S4 NON-CON (Filter floors)											
CPUS											
E1		**E2**		**E3**		**E4**		**E5**		**E6**	
3	2	4	3	4	3	3	2	3	2	5	4
2	3	2	3	2	3	3	2	2	3	1	4
3	2	4	3	4	3	4	3	4	3	5	4
2	3	2	3	3	2	1	4	2	3	1	4
3	2	3	2	3	2	4	3	3	2	5	4
3	2	4	1	3	2	3	2	3	2	1	4
3	2	4	3	4	3	4	3	3	2	5	4
3	2	3	2	1	4	3	2	2	3	1	4
	45		50		55		52,5		50		80
STS											
3		4		4		4		3		5	
2		2		3		2		4		1	
4		4		5		4		2		5	

Table E.2: Raw data (left column) and post transformation data (right column) for each evaluator's answers to the CPUS and STS questions on mobile.