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Master thesis

End-user development interfaces for creation of virtual 3D environments

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Abstract

Virtual 3D simulations in healthcare allows for training in safe environments to prepare for and assess scenarios that may occur. Such simulations however are expensive to create, maintain and update due to the professional knowledge required to develop such systems. End-user development attempts to enable the end-user such as healthcare workers without any experience in software development to create, modify or extend software according to their needs. The goal of this master thesis was to identify the current approaches for end-user creation of virtual environments and simulations and investigate how end-users could take the first step at end-user creation of virtual simulations. Based on this I have in this thesis paper conducted a usability test of two methods for capturing physical rooms using smartphone devices to create a floorplan for generating virtual environments. To perform the usability test, I used an application called MagicPlan which allows users to capture and create floorplans with either defining corners on a 2D surface or using a camera AR approach to achieve the same goal. Using breakdowns as an analytical framework, the results suggest an easier adoption using the camera method, but throughout the usability test both methods scored slightly similar in terms of accuracy and usability. The methods investigated in this thesis paper however are limited compared to professional 3D modelling software but provides the essential tools for capturing the initial shape of the room. The results suggests that end-users without any prior experience in software development managed to capture and create virtual 3D environments to be potentially further used for end-user creation of virtual simulations.

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1 Introduction

Using simulations in healthcare to educate and provide safety to patient care has been an important asset to the healthcare industry (Gaba, 2007). There are various ways of simulation in healthcare, and Gaba (2007) presents a few central categories, such as: Education (simulations for learning basic skills, or introduction to actual work), training (simulation of real-life tasks and assessment of performance of such tasks), or rehearsal (rehearsing specific procedures). Ghanbarzadeh et al. (2014) in a literature review of the usage of 3D virtual worlds for healthcare simulations labelled similar categories. In their review they divided the results found in 6 categories: Treatment, Modelling, Evaluation, Lifestyle, Academic education, and Professional education. However, developing such simulations are often done by professionals and are often very expensive. In addition, since these virtual simulations often replicate real-life scenarios and the physical environment, the software developer of the simulations would likely have to visit the location to achieve the resemblance of the physical space in the virtual environment. However, as technology increasingly improve and enhances problem solving in our everyday life, the concept of end-user development might become a possibility for allowing healthcare workers to be a part of the process of creating such simulations.

End-user development (EUD) is a set of methods, tools and techniques to empower a user with no professional software development knowledge to create, modify or extend a software artefact (Lieberman et al., 2006). The end-user is a key distinction in end-user development. An end-user is not a "casual", "novice" or "naïve" person, end-users are professionals in their respective fields (Nardi, 1993), and in this case a healthcare professional. These end-users often have short or mid-term goals they wish to achieve in their fields with the help of technology. However, end-user are often not professional software developers, nor do they have the motivation and time to develop systems at the same level as a professional. EUD tries to adapt the complexity of systems to fit appropriately the end-users skills, in which the main goal is to allow end-users to develop and adapt systems according to their needs (Lieberman et al., 2006). However, this is often hard to accomplish, and the literature explores this common challenge differently (Fischer & Giaccardi, 2006; Lieberman et al., 2006). Fischer & Giaccardi (2006) describes this challenge when discussing the idea of "Turing tar pit: where everything is possible, but nothing of interest is easy", and the opposite "Inverse Turing tar pit: Beware of over-specialized systems, where operations are easy, but little of interest is possible". Propose the concept of Meta-design as an attempt to tackle this challenge of Turing tar pit. While, in the paper written by Ludwig et al. (2017), they look at this challenge as a slope of complexity, in which the system should be designed to gently expand the end-users knowledge when tailoring and using the system, cited from the works of MacLean et al. (1990). MacLean argues that it should be as easy to modify and tailor the environment as it is to use it. Henderson & Kyng (1995) defines tailoring as a way of modifying an application based on the context of its use. It is therefore interesting to investigate to what extent can an end-user tailor an application to create virtual simulations to their contexts. These theories and challenges will be further described and presented in the theory section; however, the common challenge is how these systems should be designed and developed to support the end-users' limited knowledge and skills of software development.

1.1 Research questions

The purpose of this study is to investigate how end-users (a healthcare worker) can be involved in the process of making virtual simulations and its environment. A central aspect of this, is how such system can be developed and designed, and how can the tool support the end-user's limited knowledge of development as easy as possible. I therefore present the research question below.

RQ 1: Which type of user-interface is most beneficial to support the easy and effective end-user creation of virtual 3D environments for virtual task-training in healthcare?

Furthermore, to answer this research question, I present the historical background for creation of virtual objects and environments, the related work, and the relevant theory such as end-user development and its subfields and a specific definition of virtual environments. Following, in the Methods chapter I describe and present the current methods used in this master thesis to answer the research question. Then I present the results of this thesis paper in the Results chapter and discuss the findings in the Discussion chapter. Lastly, I conclude the findings of the study, and give my recommendations for future work in the Conclusion and future work chapter.

1.2 Historic background

In the past 30 years, researchers have studied how users can use and create 2D/3D virtual environments for simulation and problem-solving for real life problems, specifically using tools such as 3D modelling, or computer-assisted design tools. In such virtual environments, the users can explore a variety of scenarios or options with less time spent and at a low cost.

Looking back to the early 60's, technology for 2D/3D modelling have been developed mostly for assisting professional and commercial use. One of the earliest programs for 2D modelling is known to be "sketchpad" developed by Ivan Sutherland in his dissertation project (Perry, 2014). Perry brings out that "sketchpad" explored many of the fundamental ideas of 3D modelling interfaces when developed in the context of MIT's computer-aided design (CAD) project. Sutherland (1963) described his system in 1963 as a rapid man-machine communication system with the use of buttons and a light pen to create various models constructed by lines. The author explains that the use of sketchpad, reduced tedious work such as duplicating objects to create patterns would save tremendously amount of time. An example Sutherland presents is the creation of a pattern of 900 hexagons, which took one and a half hour. In contrast, the estimation by the drafting department at that time, assumed such work would take up to two days. Sutherland's (1963) work was an engineering focused system aimed to assist engineers draw technical drawings such as a bridge, an example Sutherland present in his paper. He argues that the ability to draw such illustrations would introduce the ability to experiment with different solutions or modification of existing design. However, Sutherland also investigated in the scope of an artistic lens suggesting that the system could also assist artists to create animated cartoons.

According to (Cadazz.com), the late 1960s and early 1970s CAD software began to be widely adopted and developed internally in automotive and aerospace industries, but at that time, CAD software were still 2D interfaces. By the end of 1970, the rise of CAD software had formed its position in the commercial space. During this decade, the jump from 2D to 3D tools began to emerge, especially the works of researchers like Ken Verspille, the inventor of NURBS (Cohn, 2010).

According to Cohn (2010), when the early 1980s arrived, and the invention of the operative system UNIX arrived to the commercial market, many CAD systems such as CATIA were developed. The large-scale adoption of CAD systems began when the first IMB PC arrived in 1981. Moreover, in 1983 AutoCAD by Autodesk made its debut, marking a big milestone of CAD as the software offered 80% of the functionalities of the competing software's for 20% of the cost. During the 1980s, several CAD systems with high functionality began to appear mostly still in 2D, but at the time, the computational power were still not strong enough (Cohn, 2010).

It was not until the 1990s, the computational power of PC's could handle most 3D CAD software. During the 1990s, the Cad industry were divided into four main companies, Autodesk, Dassault Systems, PTC and UGS (Cohn, 2010). Looking at today's tools, the CAD technology has transformed into various distinctions such as CAD and 3D modelling. According to Sculpteo.com (2019), the difference between CAD and 3D modelling is defined by the context of what is needed from the tools. CAD as previously defined is a way to draw and create technical 2D drawings to 3D objects to support engineering and its important factors such as precision (with tool such as Autodesk AutoCAD[1] or Sketchup[2]). While 3D modelling most used in the entertainment business. These tools (such as Autodesk Maya[3] or Blender[4]) are used to create animations, special effects, and 3D visualizations. The creator work with 3D shapes rather than starting with 2D drawings as you do in CAD software's. In the world of CAD, commercial solutions such as AutoCAD as previously mentioned, Sketchup Pro and other software are mostly targeted at professional users (Santos et al., 2011) and such CAD software's often have a steep learning curve. But efforts of making these tools more accessible for the average person have been done, Fischer (2009) states that Sketchup (owned by google at that time) is a "low threshold and high ceiling" software for developing creative 3D models. Fischer (2009) empathize that the learning mechanisms provided by the Sketchup software is an important motivational factor for users who wish to use such programs. Fischer (2009) also address that the 3D warehouse[5] is a great asset for enabling users to share and use other people's models in their own work.

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[1] https://www.autodesk.no/products/autocad/overview?plc=ACDIST&term=1-YEAR&support=ADVANCED&quantity=1
[2] https://www.sketchup.com/
[3] https://www.autodesk.com/products/maya/overview?support=ADVANCED&plc=MAYA&term=1-YEAR&quantity=1
[4] https://www.blender.org/about/
[5] https://3dwarehouse.sketchup.com/

Looking back at the history of CAD and 3D modelling, the search for improving software to support problem solving with has evolved through the years. In addition, as software and hardware have become more accessible and cheaper, ways of simplifying the steps needed to create in such tools has been a focus of research. The works of Cannavò (2020) is an example of this. In the fourth chapter in the authors PhD paper, Cannavò presents methods for automatic generation of 3D scenes based on image as input to reduce time and constraints for the user. Approaches for attempting to simplify CAD approaches for capturing and recreating physical buildings has also been researched such as (Santos et al., 2011), or use of camera technology on smartphone devices for capturing rooms such as (Rosser et al., 2015).

1.3 Related work

In this section, I will present the related work to this thesis paper, investigating the different approaches to end-user creation of virtual environments, and usages of virtual environments for creation of simulations, experiments, and learning. Approaches such as CAD-like software and other types of interfaces used to create virtual environments will be presented. To the best of my knowledge, little research has been completed in the context of healthcare in this specific problem area, therefore this chapter will include various domains.

1.3.1 Tools for end-user creation of virtual environments

Several papers have researched methods for end-user creation of virtual environments in various domains and for different usages such as (Cannavò, 2020; Pintore & Gobbetti, 2014; Rosser et al., 2015; Sankar & Seitz, 2012; Santos et al., 2011; Varlamis et al., 2000; Vosinakis et al., 2007). The papers identified also used a variety of different approaches for creating the environments such as CAD-like approaches or the usage of scanners, images, or smartphone devices.

CAD-like systems

An approach close to the CAD-like approach is the paper written by Vosinakis et al. (2007). In this paper the authors present a collaborative computer-aided design (CAD) tool for creating a 2D/3D virtual reality (VR) virtual environment aimed at creating virtual representations of rooms and placing furniture's for end-users (a customer) and interior designers to collaboratively use. The proposed web based desktop VR prototype application developed by Vosinakis et al. (Vosinakis et al., 2007), includes functionalities for modelling a room or apartment from a ground plane, where users sketch out the desired walls and the software connects the sketch and generates the walls. Furthermore, the software allows for modification of textures and colours of the walls, insertion of doors and windows, adding lights and lastly placing furniture's from a categorized library. The application includes an exocentric and egocentric view for placing objects such as furniture's or to simply explore the designed room (see Figure 1).

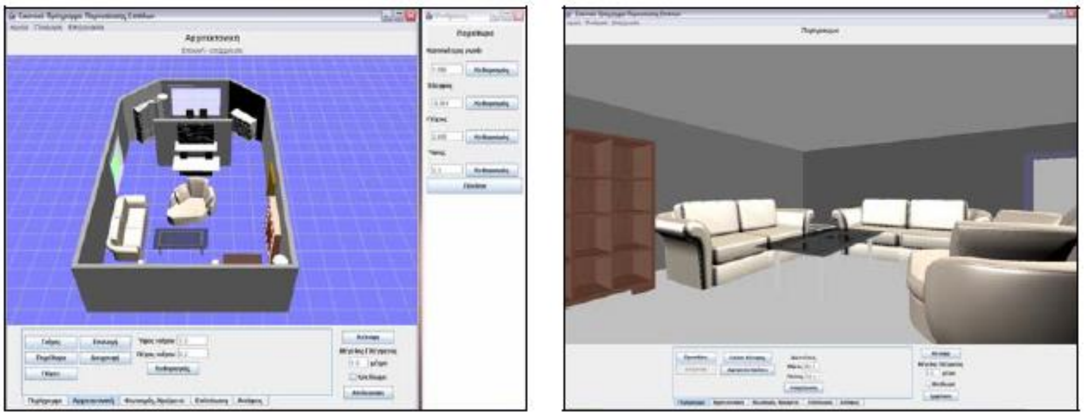

Figure 1 Interior design tool (Vosinakis et al., 2007)

During the design process for the prototype, the authors Vosinakis et al., (2007) presents a user-task analysis for the tool, where they identify three possible scenarios for using a VR interior-design environment. The first scenario are professional interior designers using professional CAD software create and decorate spaces such as planes, conference centres, hotels etc. The second are teams of professional designers asked to decorate places such as an apartment iteratively with collaboration with the client until a satisfactory result is achieved. The last scenarios are non-professional designers using the software the same way as scenario two, letting the end-user try several different concepts. Furthermore, the authors lay out five main user tasks of the process of interior design focusing on the last two scenarios, "construction and modification", "Definition of design requirements", "formation of concepts", "concept refinement", and "evaluation". These user tasks are defined for specifying the design requirements.

During the evaluation of this prototype, the authors found that the participants thought it useful as an assistant of interior design. However, lack of visual cues when interacting with the objects and delays in manipulation were found to be irritating for the user. The authors concluded that the proposed methodology helped inexperienced users to model interior environments and placing objects in an intuitive manner, focused on making the task as easy as possible. The paper did not however address if the participants were supposed to recreate a given room, and little details for how well they were able to understand how to create the room were done.

A similar approach to generating virtual environments, and specifically recreating existing buildings is the paper written by Santos et al. (2011). The authors experimented with generation of 3D structures from 2D drawings, texture selection and automatic object placement. In their paper, they describe their tool in eight steps for creating the desired house based on digital floor plans (see Figure 2). The first step is to add a digital floor plan to their tool (the tool automatically scales the digital floor plan). Step two, the user draw lines representing walls on top of the blueprint provided in step one (the tool automatically recognizes connections between walls and snaps them together). Step three includes the placement of doors and windows by drag and dropping to the desired spot. Step four the user applies materials/textures on interior, from a palette of textures. The user can also add additional textures to the palette from real-life photographs of their existing walls and upload to the tool. Step five is the placement of objects, the objects have specific classes to identify if it is specific for a wall, roof, or floor, and will snap to the surface according to these classes. The tool also includes the ability to distribute objects automatically room by room, by apply furniture based on the room type. The next step includes applying materials to exterior, step seven is the creation of the roofs, and lastly step eight, is creating the surrounding environment.

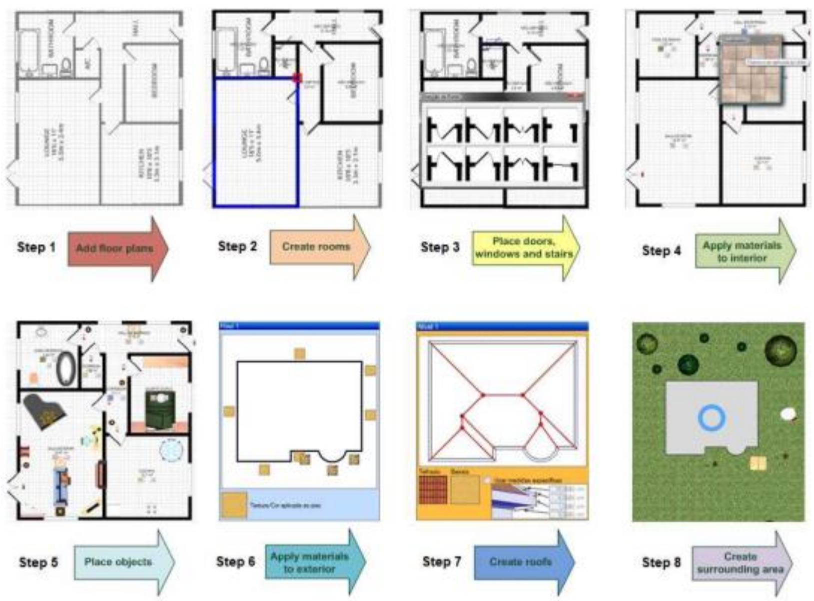

Figure 2 Process of generation of virtual building (Santos et al., 2011)

The authors discuss benefits of the tools to some extent, such as in their concluding remarks, it is suggested that the tools are advantageous for users without architectural knowledge. However, this tool lacks a thorough user testing phase, for instance, even though the authors suggests that a user can model a building in a matter of 10 to 15 minutes, very little insight to how the usability of the tool worked in practice for the user and what type of user-test were performed is presented. Instead, the testing phase of the prototype focused more on the performance of the tool. Additionally, the authors suggests that this system could be used in various domains such as “architecture, virtual games, cinema and simulation programs”. Another thing to note in this paper is the fact that the method relies on the user having access to existing floorplans. And if it is the case that a user only has access to physical floorplans, the user must digitize it before beginning.

Varlamis et al. (2000) is another example of end-user creation of virtual environments, specifically designed to allow user easier access to 3D visualisation by creating a tool open on the web (see Figure 3). In this paper however, the system is different to what Vosinakis et al. (2007) and Santos et al. (2011) can achieve. Instead, in this system a user can only apply a few parameters from shaping the room. For instance, the system only supports rectangular rooms, and the user may only change parameters for length, width, and height. Additionally, the system supports placing objects such as furniture, windows and doors from a given database. However, as with Vosinakis et al. (2007) and Santos et al. (2011), the authors focus more on the technical challenges than how the usability of the system to an end-user might be.

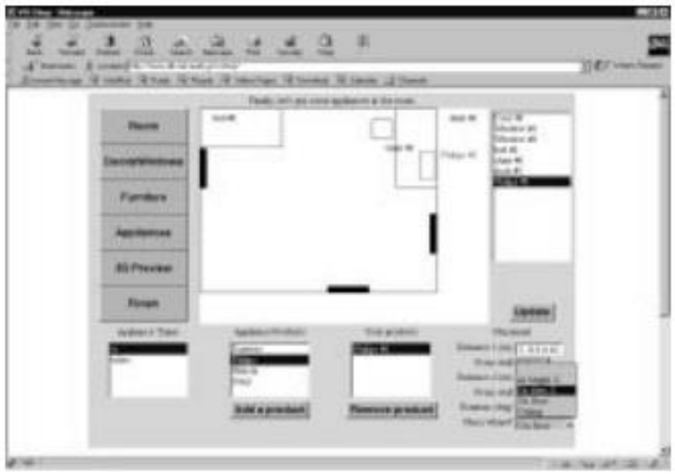

Figure 3 Interface for 3D visualization of a room (Varlamis et al., 2000)

Alternative methods of end-user creation of virtual environments

The literature has also investigated other methods for creating virtual environments, such as the use of point cloud generated by scanners (Ochmann et al., 2016; Turner et al., 2015) to reconstruct existing rooms, the use of image input Cannavò (2020), or the use of smartphones to achieve the same goal such as (Pintore & Gobbetti, 2014; Rosser et al., 2015; Sankar & Seitz, 2012).

For instance, in Cannavò's (2020) experiment "Automatic generation of affective 3D virtual environments from 2D images" in chapter 4.2 in the author's PhD thesis, the author discuss the automated process of room generation and object distribution through images as a means for rapid environment creation for end-users. The author explains that this process is divided into two steps according to (Canlin Li et al., 2009). The first step: definition of the content revolves around identifying the objects to be placed and their spatial information through a computer-based system. This information can be through various mediums such as text or even images (the goal of this paper). The second step, scene synthesis, is the aspect of generating the desired environment and objects based on information from the first step (Cannavò, 2020). According to the author, some papers address only the first step, while other papers have addressed both steps (A. Chang et al., 2014; A. X. Chang et al., 2017; Coyne & Sproat, 2001; Seversky & Yin, 2006), through the use of text as input such as. While this is similar to the goal of Cannavò (2020), the author suggests the use of text as an input doesn't represent the optimal choice for fast prototyping. Cannavò's (2020) proposed systems combines a series of stages to automatically generate the environment (see Figure 4), by first allowing the user to provide two main inputs, the mood and an image. This information passed through google cloud algorithms to make sense of the image, and then through a scene creator add-on to blender, which generates the environment.

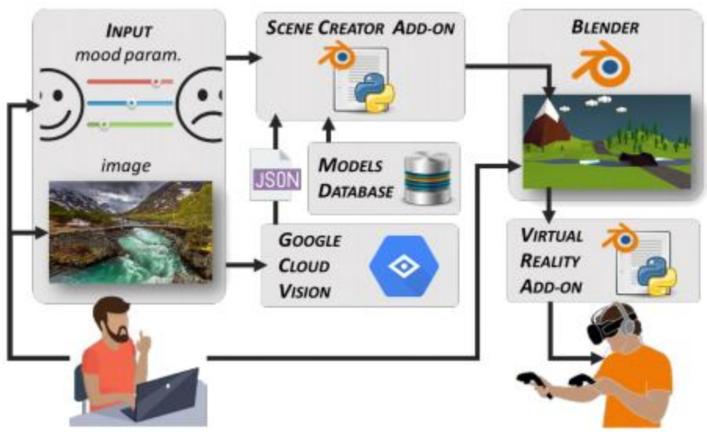

Figure 4 System architecture (Cannavò, 2020)

In the paper, an evaluation of the system with 12 non-expert users (low expertise in computer graphics) was conducted. This user study was according to the author divided into two tasks. The first tasks evaluated the usability of the system, by evaluating what the users achieved with a brief introduction to the system. While the goal of the second task was to analyse the system with three aspects to be covered, with participants asked to explore four different scenes. The first aspect, the similarity between the input image and the automatically generated scene, the second, the similarities between the input mood and the perceived mood from the generated scene. Lastly, the spatial awareness gathered from the environment. The result of the task one evaluation, the score measured on the SUS scale, indicated the system as high usability, and task two scored also relatively high in terms of remembering the object placement.

However, methods using smartphones is more aligned with the current research topic, as such scanners mentioned at the beginning of this section are often quite expensive, while the accessibility through smartphones or cameras are more likely to be more aligned with an end-users as 3,5 billion people according to statista.com own a smart phone (*Smartphone Users 2020*, 2020). This argument is also supported by Sankar & Seitz (2012) as they propose that their interface using a camera will enable casual users to capture, visualize or reconstruct their desired physical environments due to the availability of smartphones.

Using cameras and smartphones have been in the literature discussed in recent years, mainly focusing on the accuracy of its technology and algorithms (Pintore et al., 2014; Pintore & Gobbetti, 2014, 2014; Rosser et al., 2015; Sankar & Seitz, 2017, 2016). However, these papers differ from each other in terms the output reconstruction, for instance, the papers (Pintore et al., 2014; Pintore & Gobbetti, 2014; Rosser et al., 2015; Sankar & Seitz, 2012) focus mainly on recreating the floor plan and its dimensions. While (Sankar & Seitz, 2016, 2017) focus on recreating the physical environment in a virtual environment where both the 3D environment and it's objects such as furniture's are captured and recreated.

Methods for creating floor plans using camera technology

Sankar & Seitz (2012) for instance discussed in their paper the use of smartphone hardware (camera, gyroscope, accelerometer and magnetometer) to capture indoor scenes such as own homes to generate a twofold system for the virtual environment: 1. An interactive tour, 2. a generated 2D floor plan. To achieve this, the user systematically complete five steps (see Figure 5). The first step is data acquisition: the system directs the user to rotate 360 degrees to capture the room through a video and once that is completed, the user then is prompted to move to the next room. This process is repeated until all the rooms are captured. The next step allows for a complete playback mode of the virtual tour, enabling the user to virtually interact with the captured environment by moving through the environment and 360 images. Step 3 is then allowing the users to embed additional content (extra images or texts) to points of interest by tapping the desired location. The next step is then to mark features of each individual room such as walls and doors in a playback mode. This is achieved through marking the edge of the wall in the panorama and dragging a marker across the wall to the other edge of the wall. Once step 4 is completed, the system uses an algorithm to generate the 2D floor plan. The user can then fix errors that may occur during the generation, by realigning the walls manually. The last step, the user interface allows for 3D rendering of the virtual environment by automatically extruding the walls generated in the 2D floor plan (Sankar & Seitz, 2012).

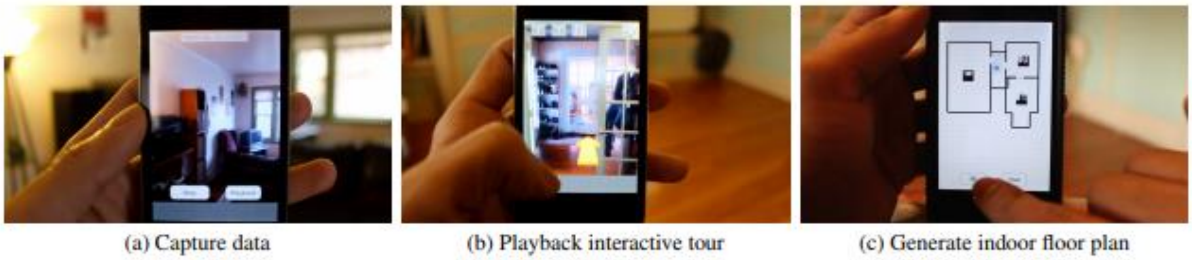

Figure 5 Indoor capturing process (Sankar & Seitz, 2012)

The authors argue that their proposed system should be more accurate than MagicPlan[6], the system they used to evaluate their results with. The argument for this is that MagicPlan uses an augmented reality interface that allows for marking floor corners and then estimate the dimensions of the room. According to the authors, the problem is then when furniture's obstruct the corners which forces the users to make a guess where the corners will be. To analyse the proposed system, Sankar & Seitz (2012) created a ground truth of what the 2D floor plan was, then evaluated the accuracy of their proposed system by placing their result on top of the ground truth, and the same with the result of the MagicPlan interface. The results indicated that the proposed system achieved slightly more accuracy than the MagicPlan interface did, even though it took slightly longer to record the environment. This may be irrelevant as the difference is a matter of 20-30 seconds between the two. This was however also predicted previously in the paper, as the authors explain that the sole purpose of MagicPlan is to provide a digital floor, while their system is to provide that and an interactive tour.

Giovanni Pintore & Gobbetti (2014) present in their paper, a similar approach where the system is divided into two components, scene capture and scene processing. Scene capturing revolves around gathering the data through the scope of a camera, while scene processing uses the input data to construct the virtual

[6] https://www.magicplan.app/

environment. During the scene capture, the user uses a mobile camera to record a 360-degree video of the environment and records a corner when in vision by clicking on the screen. Similar to Sankar & Seitz (2012), the authors analyse the accuracy of their model without much insight to the user-experience of their system. Another similarity is that they propose their system achieved better results than MagicPlan, for the same reason as Sankar & Seitz (2012) mentioned (furniture's obscuring the vision of the camera). Additionally, G. Pintore et al. in (2014), the same year Giovanni Pintore & Gobbetti (2014) published their paper on "effective mobile mapping of multi-room indoor structures", they improved on this technology by reducing redundancies in their method of data capturing.

Similar to the examples stated above, Rosser et al. (2015) also use a mobile device to achieve the same goal, but using a slightly different technique. Instead of using the camera to record a 360 video, this system allows for panorama scanning of the room, then marking corners at the floor level through an augmented reality visual feed (see Figure 6).

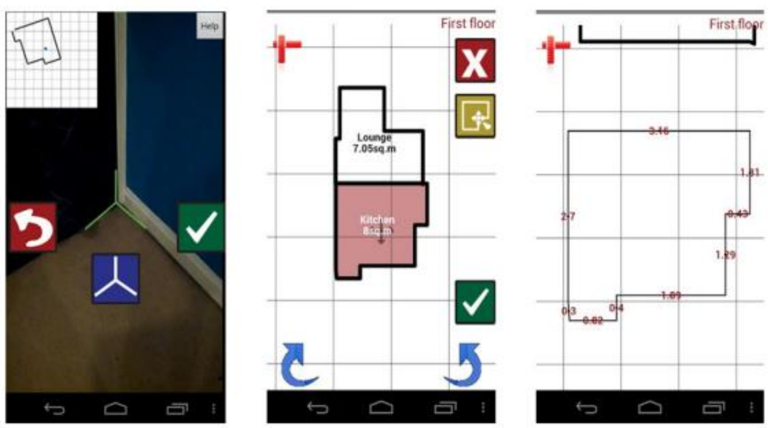

Figure 6 Room creation tool (Rosser et al., 2015)

Even though papers like (Pintore et al., 2014; Pintore & Gobbetti, 2014; Sankar & Seitz, 2012) argue or propose that their methods of creating virtual environment should be an easy and accessible task for casual users, neither of the papers directly discuss or experiment how the "casual" users actually perceive the interface.

1.3.2 Tools for end-user creation and learning in virtual environments

Several papers have also researched different approaches in context of using existing virtual environments creating simulations to learn or using tools to learn domain knowledge when designing within the environment.

Designing in virtual environments

For instance, Fischer et al. (1990) presents in their paper the domain knowledge-based tool, for constructing residential kitchens. This tool named "Janus" contains a palette in which the user can choose kitchen objects from, such as stoves and countertops, and a catalogue where predefines kitchen plans can be chosen by the user to reuse or modify. Additionally, the tool has a work area and a message panel where the system provides critique/feedback to the end user's proposition (see Figure 7). The critique feedback is a central aspect of Janus, this system uses a cyclic critique approach where the user proposes a model for the system to interpret and gives feedback to the user according to domain expertise. An example given in the paper, Fischer et al. (1990) explains that the system will critique the proposition from the user, if the user chooses to place a stove in front of a window, as this constitutes a fire hazard.

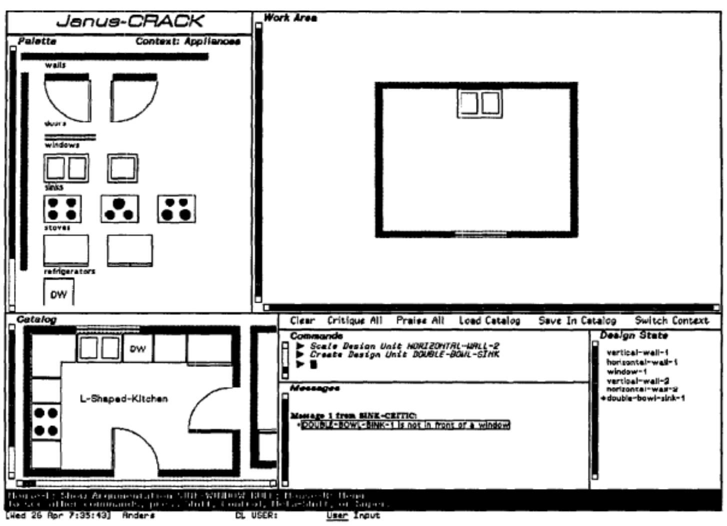

Figure 7 Janus kitchen planner tool (Fischer et al., 1990)

The IKEA kitchen planner is a similar kitchen design tool as Janus presented by Fischer et al. (1990). In the paper written by Yu (2017), the author investigate how the kitchen planner in the context of social-cultural differences in countries (specifically Sweden, USA and China) in respect to affordances (specifically social-affordance) and uptake, material factors, and technological features. Yu (2017) defines to affordances as “a relationship between the properties of an object and the capabilities of the agent that determine just how the object could possibly be used, in which both the quality of the object and the abilities of the agent jointly determine the presence of an affordance” from the book written by Norman (2013). Yu (2017) exemplifies the concept of affordance with how the shape and material of a door handle would propose the action of opening the door. In respect to the definition of affordances Yu (2017) further extends this on a three-level structure, operational level (properties of the physical aspect of the technology, i.e. keyboard), instructional level (traits and properties that support the goal of the action), and social affordance (properties that support activities in social and cultural contexts) defined by (Sun, 2006, 2012). Yu (2017) uses the term uptake as a way of gathering insights to technology as technology enforce social actions. The author provides the definition of uptake as understanding an action based on illocutionary speech, from the book *How to do things with words* (Austin, 1962). Yu (2017) Exemplifies this by how one would understand to clean a table, if one would say, “this table is messy”.

In respect to these definitions, Yu (2017) argue that the IKEA kitchen tool fails to sustain affordances on various levels, such as language, social affordances. In terms of language, the author comments on the tool to not consider for other languages in the English version of the tool, and the lack of the metric system. Furthermore, the author argues that the tool promotes the kitchen as a social area, in which the Chinese culture contest.

Furthermore, the Yu (2017) reflected on the user experience such as learnability, efficiency, memorability, accessibility and satisfaction. The analysis explain that the tool is categorized in respect to interior, these categories are Room layout, work zone solutions, kitchen and appliances, dining tables and chairs, and “your list so far” (see Figure 8). The author explains that the tool by IKEA requires low technical requirements (CPU/GPU load) and a minimalistic interface. The author argue that the software’s interface is designed in such a manner that the user can easily navigate by proper symbolling and cursor control. The author also advocates the use of templates in the tool helps to accomplish the users’ goal by boosting the productivity. Furthermore, Yu (2017) states that the IKEA system planner assists the users to visually represent their conceptual kitchen by presenting images and measurements of the furniture pieces on the interface. The author also argues that the tool itself may not fully achieve the user's goal to purchase the furniture's through the software, but the author argues however that the tool itself is a good practice tool for interior design. The author also applauds the tool in respect to intelligent functions, specifically the software's ability to identify problems and suggest solutions such as asking the user to add extra features to the furniture if needed.

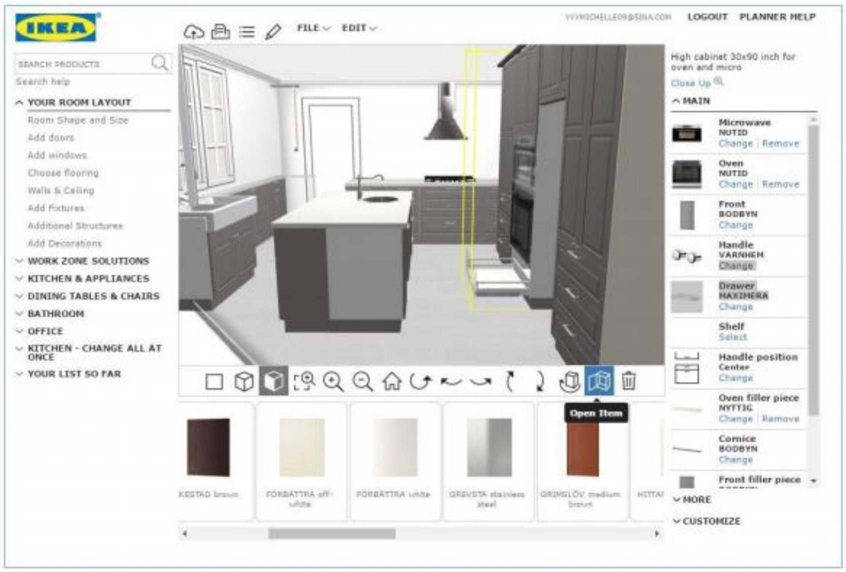

Figure 8 IKEA Kitchen planner (Yu, 2017)

End-user creation of experiments

Zhong & Liu (2014) propose in their paper a domain-specific system for chemistry experiments in a virtual world. The system called iVirtualWorld was designed for end-users to create virtual chemistry experiments in a domain-oriented 3D virtual experiment design environment. The goal of the authors is for teachers (domain-experts) to create the environment for chemistry experiments and in a reasonable timeframe for students to interact with, and are the participants satisfied with the result, meaning, do they find the system easy to use/learn and useful. IVirtualWorld's interface are divided into two dimensions. The first is the initialization of the experiment, where the domain-expert is met with an interface including an inventory (see Figure 9). This inventory panel contains 3D objects such as beaker and test tube can be found. Then an empty field panel representing the table where the users can drag the items from the inventory. Lastly, the interface includes a settings panel to each of the object such as can it be moved? Alternatively, how much does is weigh? The second dimension is the simulated virtual world, where the user can interact with the placed objects from the first dimension, and conduct experiments. Based on the results of the study, Zhong & Liu (2014) argue that the use of the tool could improve the pre-lab sessions in terms of increased interest, introducing new instruments and explain the content of the procedures in a more visual and dynamic matter. Another thing the authors note is the fact that virtual simulations take significantly less time to conduct, i.e., an organic reaction could take up to 48 hours in the real world, but in the system, it could scale the time frame accordingly. However, when comparing the virtual experiment to real world experiments, the results showed that the students thought that it could not replace the real-world experiments. Reason for this is that some object requires hands on experience.

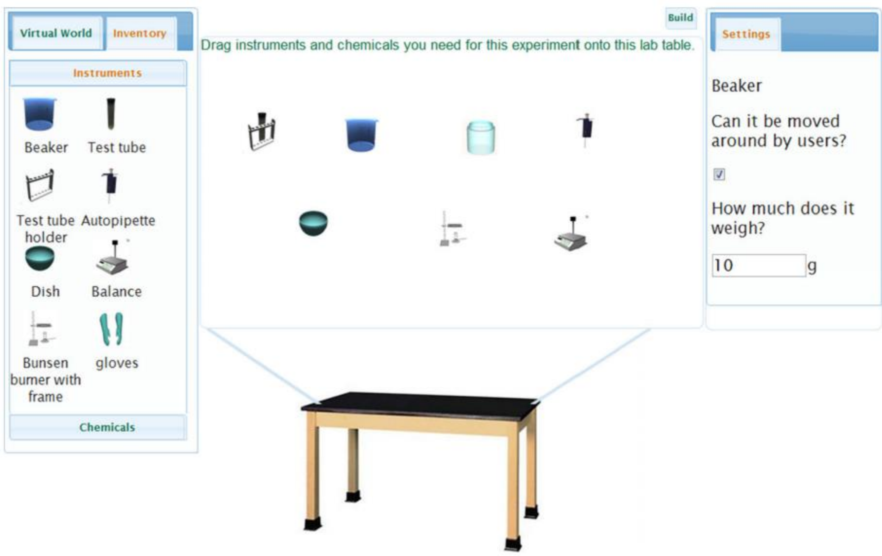

Figure 9 iVirtualWorld (Zhong & Liu, 2014)

Another example of end-user creation of experiments is the paper written by Vasser et al. (2017). In this paper the authors explore the concept of experimenters to create virtual environments, specifically experiments regarding “change blindness” and “false memory”. In this paper, the author describe how they made a toolbox for the Unity game engine to create virtual rooms with furniture’s, which can be modified according to the experiments (see Figure 10). Once the virtual environment (experiment) is created, the participants can then enter the virtual environment and participate in this experiment. One example is the “change blindness” experiment, where the experimenter created multiple clones of a room, where some objects were adjusted or removed to then investigate if the participant would notice. Their idea and goal of the project was to empower researchers to create experiments in VR with limited knowledge of game development in the game engine Unity.

Figure 10 VREX: Three stages. 1. Create room, 2. Define experiment, 3. Participate in experiment (VR) (Vasser et al., 2017)

1.4 Theory

1.4.1 End-user development, tailorability and gentle slope of complexity

End-user development (EUD) is a set of methods, tools and techniques to empower a user with no professional software development knowledge to create, modify or extend a software artefact (Lieberman et al., 2006). An end-user is differentiated from a conventional programmer by Nardi (1993) in his book “ A small matter of programming: Perspectives on end-user computing”, with a key distinction. Nardi states this distinction as “programmers like computers because they get to program, and end users like computers because they get to get their work done”. The author describe end-users as people such as “chemists, librarians, teachers” etc.… with desires and needs to use computers seriously in their workplace. Costabile et al. (2003) gives a similar explanation of EUD, as the range of user participation of software development in which the tasks are transferred from traditional programmers to the end-users (the domain-experts) themselves. The authors describe the range of user participation from "providing information about requirements, use cases and tasks, including participatory design, to end-user programmer".

End-user development attempts at enabling end-users to design, tailor or customize the software's functionalities and interface by allowing the end-user to modify existing software to fit their current needs (Ludwig et al., 2017). Won et al. (2006) refer to Henderson & Kyng (1995) when defining tailoring as: "the activity to modify a computer application within its context of use". The concept of user-tailorable computer systems is discussed in the paper written by MacLean et al. (1990). The author uses a mountain as an analogy for describing how end-users can tailor the system at hand to their own needs, such as changing parameters or to use a programming language. The author divides this "Tailorability-mountain" into three inhabitants, the worker (Casual worker with no intentions to learn to tailor a system, wants to get the work done), Tinkerer (Enjoys exploring the computer system, but does not necessarily understand it), and the programmer (has formal training or understanding of programming). The challenge is therefore to give the worker with no expertise in computing a chance to learn incrementally and easy as the worker explores the system. In the paper by MacLean et al. (1990), they explore the concept of tailoring by developing a system called "button" which is regarded as the first "highly tailorable prototype" by Won et al. (2006), focused creating an interface based on modifiable buttons (changing labels, graphical images or aspects of the actions). Maclean et al. (1990) suggests that the Tailorability-mountain needs to be gently sloped for end-users to incrementally learn by each step, whereas in programming the learning gaps are often more steeper and challenging, especially for a novice user.

Mørch (1997) extends the definitions of tailorability into three levels, "customization", "integration", and "extension". Mørch explains "customization" as a way of modifying objects' appearance or values (such as menus, buttons etc.) through selection of predefined options. Secondly, the author explains "integration" as a higher level of tailorability, such as adding new functionality to an application without specifically access the underlying code, but rather joining predefined components across the application. At the highest level of Tailoring, Mørch presents "extension", as an approach for adding functionalities to an application by improving and adding new code to the existing code. Ludwig et al. (2017) provide a similar description to tailorability as Mørch, based on the slope of complexity, the tailorability mountain and language layering (Won et al., 2006; Wulf, 1999). The authors present what they refer to as the "tailorability staircase" as an extension of EUD to focus on not only software, but also any kind of tools. At the lowest level, they introduce "use" as the action of using a tool provided without modifying its behaviour. From this point, the authors provide a similar perspective as Mørch (1997), by introducing "parameterization/customization" as the action of selecting a variety of options provided by the tool. Following, "recomposition/integration" is defined by the authors as "adding new functionality to a tool by integrating it with other tools or recombining existing components of a tool". Lastly, they explain "extension/altering" as "adding new functionality to a tool by extending it, creating new components and adding them to a tool or altering the already existing components it is made of".

1.4.2 User activities in EUD

Lieberman et al. (2006) divides EUD into two end-user activities from a user-centred perspective, "Parametrization or customization" and "Program Creation and modification" (see Table 1). The former revolves around how end-users can choose alternative behaviours in a system available by the application. Adaptive systems are those who adapt to the end user's behaviour. While the latter, are activities end-users modify or create from scratch of existing software artefacts.

Parametrization or customization	**Program creation and modification**
Parametrization and Annotation	programming by example, Incremental programming, model-based development and extended annotation or parametrization

Table 1 end-user activities of EUD

Lieberman et al. (2006) furthermore categorize other activities into the two defined activities mentioned above. In the first set of activities (Parameterization or customization), the authors place the concept "Parameterization" and "annotation". Parametrization activity is defined as when a user instructs systems how to handle certain data or functionalities. Annotation is referred to end-users adding comments to existing data or results, to achieve order and structure. In the second activity category (Program Creation and Modification), the authors place the activities: "programming by example", "Incremental programming", "model-based development", and "extended annotation or parametrization". The authors cites Lieberman (2001) when describing programming by example, and define this activity as end-users providing examples to the system and the system learns from the examples. Furthermore, the authors describe Incremental programming as a method close to traditional programming, but more concerned about modifying small parts of a program. The authors then present model-based development from the book written by Paterno (1999) as a method where end-users suggests a conceptual description of the intended activity, and the system generates the corresponding interactive application. Lastly, the authors define extended annotation or parameterization as a method for discovering new functionalities based on annotated data or from modifications, other people have shared in repositories.

1.4.3 Meta-design in EUD

The baseline for proposing Meta-design, Fischer & Giaccardi (2006) argue that software has to evolve with the user, as domain-experts are more concerned with their work and not the technology resulting in the possibility of changing software. The authors therefore propose Meta-design, where the domain-experts (end-users) become co-designers in both design time and use time. In meta-design the domain-expert is presented with tools, opportunities, and social reward structures for empowering the user to create and contribute their own visions and objectives. The author proposes the SER-model (Seeding, Evolutionary growth, and Reseeding), a process model for allowing designers to design software supporting end-users to design their own vision when using the software. The first stage, seeding, is referred to building open software seeded with domain-knowledge that can evolve during use time, instead of building close systems where the design of the software is already decided. The next phase, evolutionary growth, the seed are used to problem-solve, with developers not directly involved while users design solutions to the problems. This phase not only provides users to solve problems based on the current tools in the seed, but the tool repository of the seed is also updated after the third phase based on new information gathered during use time. The last phase, reseeding, refers to organizing, formalizing, and generalizing the information and artefacts created and gathered during the evolutionary growth phase.

1.4.4 Types of Virtual Environments

To specify the meaning of virtual environments in the context of the research questions, I will provide a definition of virtual environments. Dalgarno & Lee (2010) informs that the use of 3-D simulations, games and virtual environments for teaching and learning purposes is seen a great potential, as they provide a medium for a rich learning experience by virtual construction or manipulation of objects, exploration, and structures and metaphorical representation of ideas. Dillenbourg et al. (2007) argue that the seven different features provided in their paper can identify a Virtual learning environment (VLE). Firstly, they define a VLE as a virtually designed information space, concerned with the architecture of information. Secondly, the authors define a VLE as a social space where they argue that a web page does not represent a VLE unless it is being discussed across multiple users, creating a social interaction around the information. Thirdly, a VLE is not restricted to what type of representation of the VLE, but it must be explicitly represented; it can range from a text-based interface or a complex 3D environment. What the authors are more concerned about is how the students use the given information. The fourth feature the author presents, they look at the students as actors in the environment, where knowledge is shared across the environments. Fifth feature revolves around the idea that a VLE is not restricted to distance education. Meaning VLE is a great method for learning across various distances to the educational area. Sixth feature is the idea that a VLE embraces a vast number of different technologies such as communication, collaboration, or learning. Lastly, the seventh feature explains that a VLE must integrate and overlap with the real world and tools.

Dalgarno & Lee (2010) defines a 3D virtual environment as an environment that use the cognitive skills of human perception and applying them. In a virtual setting, in which the environment stimulates the users to interact with information. In the paper written by Dalgarno & Lee (2012), the authors presents 10 categories of learning activities in 3D VLE's, in which each of them are not mutually exclusive. These categories are, place exploration, concept exploration, Task practice, Role-play, Communication, Slide show, building or scripting, Instruction, and Machinima. The categories *place exploration, task practice,* and *Building or scripting*, are the ones most relevant to this study. Dalgarno & Lee (2012) defines *place exploration* where users visit simulated representations of the real world. Furthermore, the authors define *task practice*, as the activity where the users focus on practicing real life procedural tasks in a virtual simulated environment. *Building or scripting* category is defined by Dalgarno & Lee (2012) as an activity where users construct and place objects and environments within the virtual world. When referring to virtual environments later in this paper, it is related to the category of place exploration (simulated representations of the real world) and building or scripting within such simulations.

1.5 Summary

In this chapter, I have introduced the problem statement, addressed the concept of End-user development and presented it in the context of domain experts and virtual simulations, more specifically the end-user creation of virtual environments and simulations. I also addressed the historical background of CAD-systems to its modern time. Throughout the literature review, it was identified that the methods to create virtual environments, placing objects and creating simulations varied in terms of approaches and little research focusing on the user-experience have been completed to the best of my knowledge. It was however, identified that the methods for creating the environment were somewhat similar, and can be divided into two approaches. The first approach is described as CAD-like systems using traditional methods for creating virtual environments with levels of tailorability for the end-users by drawing floorplans and generating the shape of the room, while the second method revolves around the usage of mobile cameras and scanners to achieve the same goal. To the best of my knowledge, both methods are discussed in the literature as beneficial for end-users such as interior-designer, contractor, teacher, or other domains, but not much have been discussed regarding the user-experience of each method. However, the first method is discussed slightly more than the latter, as some of the literature discuss the usability of the tool, but not as a primary goal of the paper. While the second method is mostly discussed in the literature related to the technology's accuracy in a quantitative approach related to other previous work. I therefore in this master thesis, use this lack of investigation regarding user-experience in such system as an opportunity to explore which type of approach could be suitable for an end-user, and if such approaches support the end-user creation of virtual environments. Meaning, I will primarily investigate how to capture and create the virtual environment only, and not the interior and the end-user development of virtual simulations.

2 Methods

In this chapter, I describe and present the current methods and procedures to answer the research question for this master's thesis. This chapter is divided in two sections, firstly I present the design method, describing the approach for the prototype design and evaluation. Secondly, I present the current research methods for data acquisition and data analysis.

2.1 Design method

In interaction design, there are four main activities; these activities are *Discovering Requirements, designing alternatives, prototyping,* and *evaluating.* The first activity includes methods to discover and define new ways of interaction to the target users that could benefit and support them in the real world (Sharp et al., 2019). Methods to achieve data gathering ranges from examples such as interview, questionnaires, observation, or a combination of methods. The second activity is divided into two subcategories, conceptual design, and concrete design with the main goal to address and explore solutions. Prototyping involves using various methods (such as storyboarding, low-fidelity prototypes, Wizard of Oz, or High-fidelity prototypes) to make or use an artifact that resembles the interaction, and the look and feel of the final product to evaluate design alternatives. This evaluation is achieved through the interaction of the artifact by the targeted user, which leads to the last activity, evaluation. In this activity, the product's usability and acceptability is determined or the design is measured in the context of usability and user-experience criteria (Sharp et al., 2019).

During my investigation of the literature, it was identified that using various methods of creating virtual environments deemed beneficial for various domains. However, the variations of these methods have, as stated previously not been thoroughly investigated in terms of usability and user-experience to the best of my knowledge. Since many of these methods vary in terms of tailorability of creating virtual environments, I decided to investigate (see summary of introduction chapter) two distinctive interfaces using smartphone devices (The CAD-like approach vs Camera AR technology).

2.1.1 The prototype

By definition, "a prototype is one manifestation of a design that allows stakeholders to interact with it and to explore its suitability" (Sharp et al., 2019). However, there are various forms of prototypes, ranging from paper-based storyboards (low-fidelity prototype) to complex software (high-fidelity prototype). According to Sharp et al., prototypes answers questions and address design choices, and can be used in a variety of purposes such as testing a specific technical feature to clarify its purpose, or to specify whether a design direction is suitable for the development of the product (2019). In the bigger picture the goal is to develop an EUD tool enabling end-users to create the virtual environment, and to create the virtual simulations within this environment. However, in this master thesis (as explained in the summary of introduction chapter), I will primarily investigate the design choice of what interface is most suitable for an end-user for capturing and creating virtual environments.

A rapid prototype is defined by Avrahami & Hudson (2002) as typically low-fidelity in its nature, using rough and cheap materials often with a specific aspect of a technology to be addressed or to explore a piece of a solution. As stated previously, the goal of this thesis, is to investigate exactly this, “a specific aspect”, and in the investigation, I will be using a commercially available application made for contractors called MagicPlan, to assess the two different approaches of end-user creation. Reason for this, is that the application provides methods for creating floorplans using two different approaches in its system architecture. The system architecture and goal of the application is not however my area to address, but rather to use the applications platform to address the two different approaches of creating virtual environments.

MagicPlan

In the related work various approaches of creating virtual environments, and specifically capturing/creating rooms such as CAD-like software mostly used computers while the camera methods used smartphones. As stated in the related work section, as an attempt to enable the end-user with an easily accessible hardware I use an application called MagicPlan available for smartphones. MagicPlan (*Construction & Floor Plan App For Contractors | Magicplan*, n.d.) is a commercially available application designed and made for contractors according to their website for creation of virtual floor plans. Allowing for easy capturing floor plans, measurements, sketches, photos, mark-ups, and notes to be easily stored in the cloud using smartphones. According to the mobile application, the user interface allows for either creating the environment by placing points or dragging to other points on a flat surface (see method 1 in Figure 11). Alternatively, the user can choose to use the mobile camera augmented reality to place corner points (see method 2 in Figure 11). The contractors can use this application to provide the office or clients a quick capture of the desired environment at ease. Once the environment is captured after using the application, the user can then export the project folder to a 3D object file using the file format “.OBJ” which is a highly standardized file format for 3D objects. For instance, MagicPlan integrates with Floorplanner[7], a tool used for planning and decorating virtual 3D spaces.

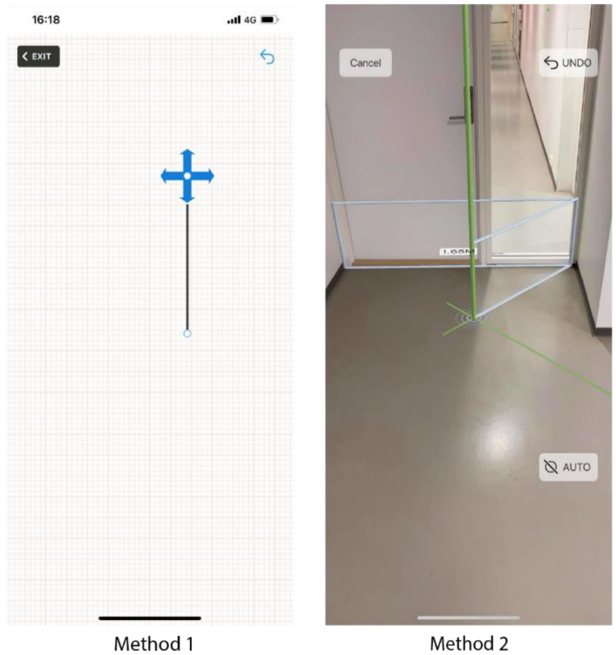

Figure 11 Methods for creating the virtual environment using the MagicPlan application.

Both methods require the user to perform certain tasks that is described below. But first, it is important to address how I refer to each method throughout the thesis to make it clear. For method 1, is from this point referred to as the “drawing method”, while method 2 is referred as the “camera method”. Another thing to note regarding objects such as windows and doors. When capturing the room, the user only captures the walls, even though these walls contain doors and windows. To apply these objects, the user could later add these in, but the main objective during the usability test was only to capture the measurement and shape of the room, and not the objects within to investigate which of the two approaches was most suitable for the end-user. Another important aspect to note is that MagicPlan does not include complex 3D modelling as Maya or 3DstudioMax would for instance and based on this be limited in terms of complexity of what can be captured.

[7] https://www.magicplan.app/integrations/floorplanner

Drawing method

The drawing method is a 2-stage method that require a user to first place corners points on a 2D surface grid in the interface by simply tapping on the desired spot on the grid with their finger. This flat surface is a grid where each square block is 1 meter in real life, and the user may zoom in to adjust in greater detail or the user may zoom out to get a greater overview. Once the user has connected all the corner points, stage 2 will appear. In this stage the user may choose to alter the measurements of the walls.

Stage 1 define corners.

As stated above, this stage requires a user to place down points to draw out the shape of the room to be created. This is achieved by first placing one corner point, then placing a new corner point (see first and second image on Figure 12). This results in a wall being drawn, and this process is repeated for each wall of the room until the shape is complete. During each placement of the corner point, the user may also adjust its position by simply pressing on the corner point, resulting in a green highlight on the corner point cross (see third image on Figure 12). Once a corner point is placed, all previous corner points cannot be adjusted until the user reaches the finalize stage unless the user chooses to press the undo button. This button simply undoes each action the user performs. For instance, if the user chooses to adjust one corner point, the user may click on the undo button, and the corner point will be adjusted back to its original position. However, the application only stores a certain amount of undo actions.

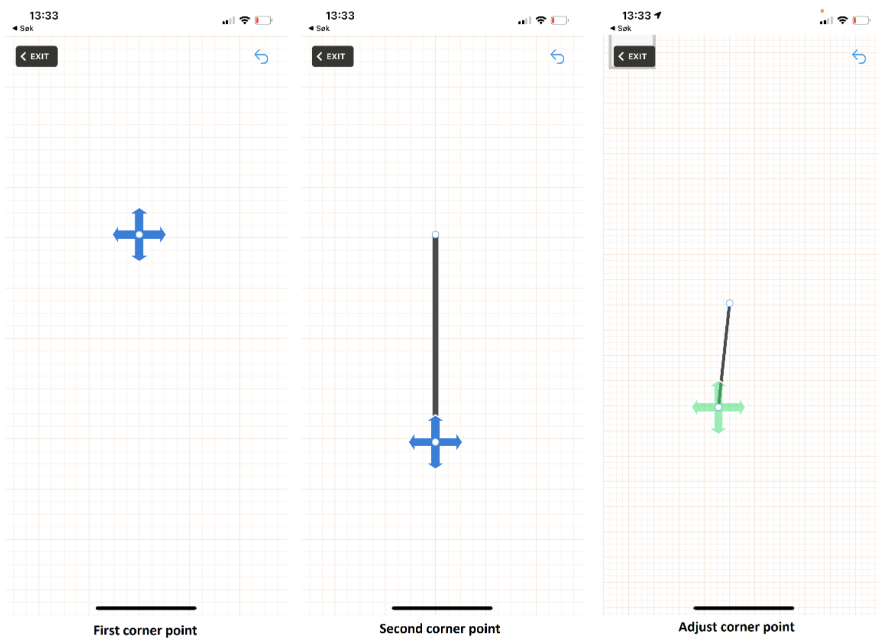

Figure 12 Drawing method interface.

Stage 2 finalize.

As previously mentioned, once the shape of the room is completed, the user will reach a finalize stage, in this stage the user may choose to alter the measurements of the room. At this point the user can see the total lengths of each wall. Important thing to note is that, in the drawing method, the only way to measure the length of the walls is by using the grid, and then reaffirming the measurements in this stage. Without any real-life measuring tools or other floor plans, most of the measurements are based on intuition such as eyeballing or using foot lengths. In this stage however, the user may want to adjust the shape and walls of the room with different methods, firstly a user can adjust a complete wall by itself by tapping on the desired wall and then adjust it (see the second image on Figure 13). The user may also after tapping on the desired wall, add another corner point to apply more shape in the room. The use of this may be applied if the user forgot a corner point for instance. Furthermore, the user may also adjust each corner point by tapping on the desired point and adjust it accordingly (see third image on Figure 13) the same way as explained in the third image on Figure 12.

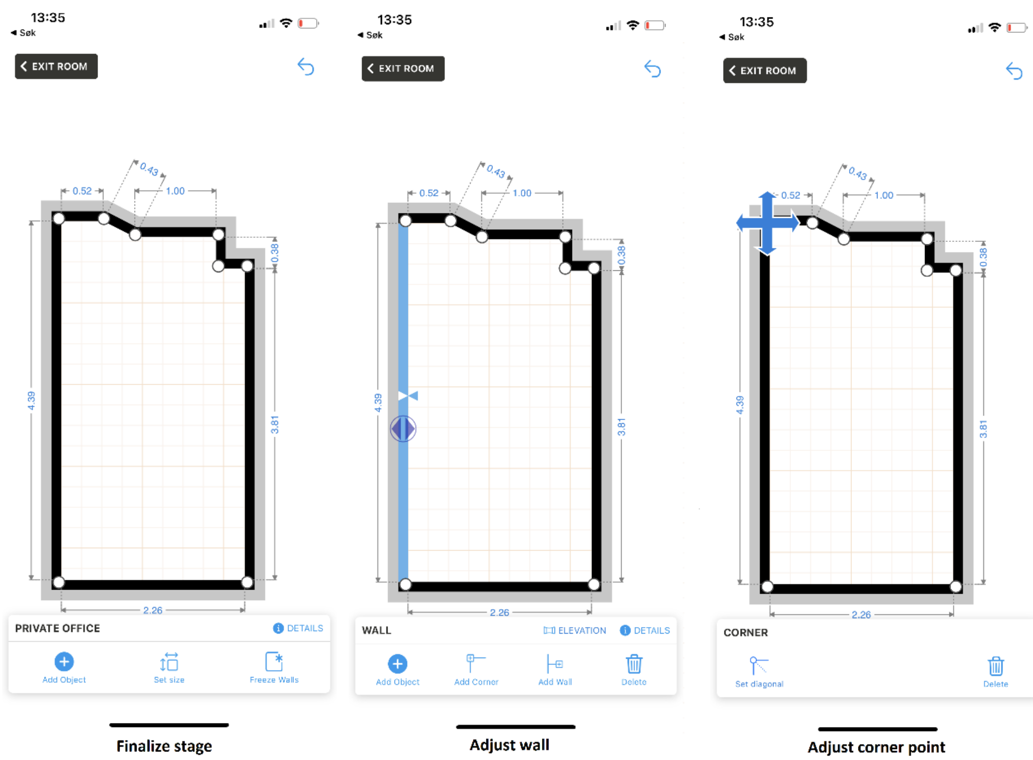

Figure 13 Finalize stage.

Camera method

Stage 1 initialize the camera.

Once the user starts with the camera method, the user is presented with instructions by the application to move the camera to start. In doing this, the application may analyse the proportional sizes of the walls and reference points (see Figure 14). If the camera is not able to initialize, the user will be presented with further instructions such as “aim at your feet”, or “slow down”. Once the camera has initialized, the user is presented with a feedback stating, “ready to go!” with the green stick appearing (see third image on Figure 14).

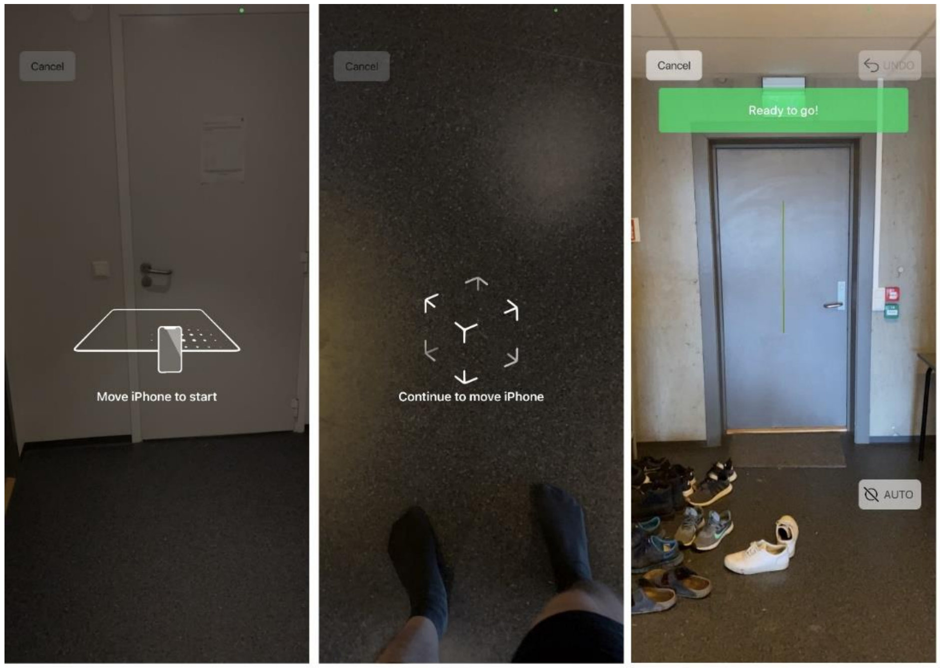

Figure 14 initialize camera.

Stage 2 scan corners

Looking at Figure 15 the user is given a green pole in which the user must position in each corner at the floor in the room. Once the pole is in position, the application may recognize that it is a corner and automatically set the corner point. However, if the application does not recognize the corner, the user may also tap on the screen to place the position by themselves. Like the drawing method, this process is repeated until the shape of the room is captured and the user may also click on the undo button in the top right corner if the user wishes to so.

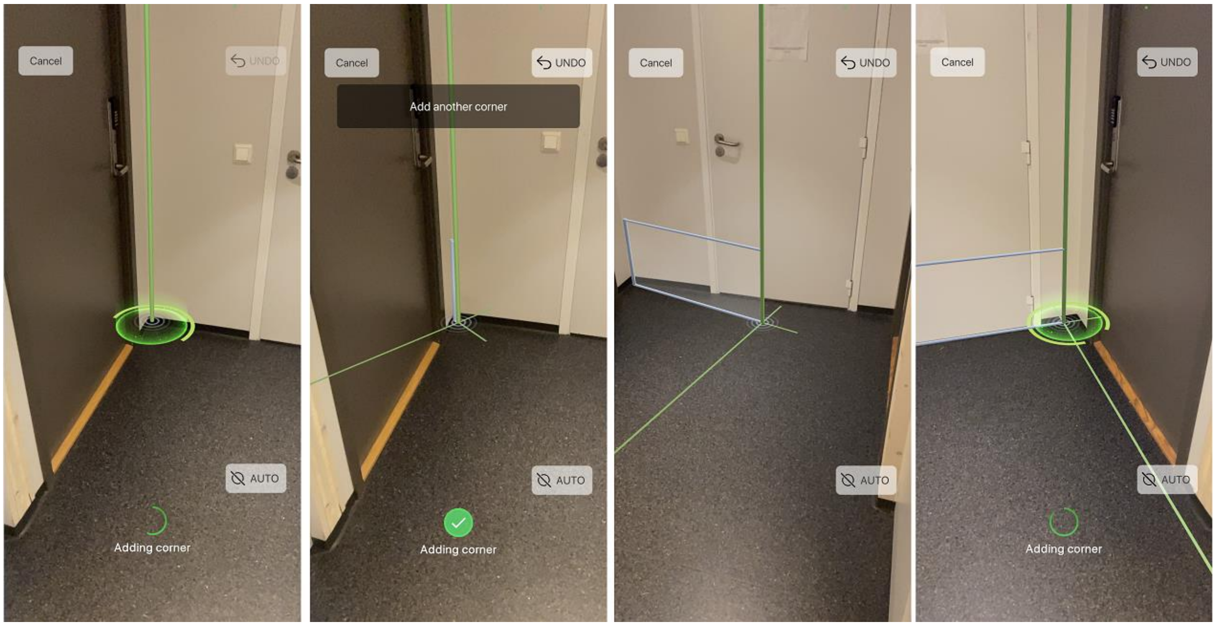

Figure 15 Placing corner points.

Stage 3 define ceiling height.

Once the shape and measurements are captured, the user is presented with the third stage, which instructs the user to aim the camera at the desired height and tap the screen to capture the wall height of the room (see Figure 16). Once the ceiling height is set, the user is notified that the scan is complete, and the user may now click on done, which leads the user to the last stage, finalize.

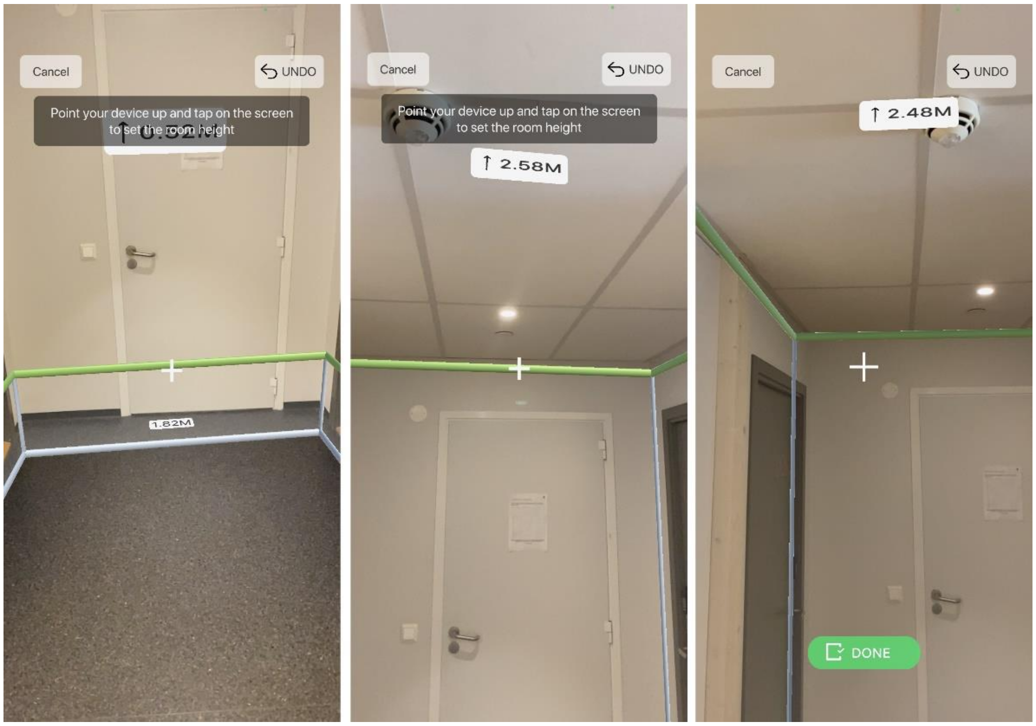

Figure 16 Setting ceiling height.

Stage 4 finalize.

Once the ceiling height and shape of the room is captured, the user will be presented with the same finalize stage as presented in the drawing method explanation. This stage is identical in both methods, and the explanation presented above is therefore sufficient.

2.1.2 The evaluation

As stated above, an evaluation is an activity of the design process the researchers collect and analyse data for the design artefact (a prototype, sketch, app, or a component of a system) in the context of the users experience with the artefact. The main goal is to address improvements of the artefact, with focus on both the usability of the artefact and the users' experience (Sharp et al., 2019). As stated above, I have in this master thesis evaluated two types of methods for creating virtual environments. According to the authors Sharp et al., there are three broad categories for evaluation*: Controlled settings directly involving users*, *Natural setting involving users*, and *Any settings not directly involving users*. The first category revolves around controlling participants to use the artifact to test hypothesis or, observe and measure certain behaviour. In this category, the main methods are usability testing and experiments. The second category is defined as a method for observing users' involvement with the product in the real world, with no involvement from the researchers, with the main method as field study. The last category, involves experts such as consultants or researchers to critique, and predict usability problems to an interface, with the main methods as inspections, heuristics, walk-throughs, models and analytic (Sharp et al., 2019).

Since the output goal of this master's thesis was to determine what type of interface is most beneficial for the end-users, the first category, *Controlled settings directly involving users*, was most suitable. This type of evaluation is divided into two subcategories according to Sharp et al. (2019). As stated above these are usability testing and experiments. Usability testing revolves around investigating how the users perform certain tasks, in which the researchers can investigate the time and errors it takes to perform said task. Or the researchers can gather data such as the opinions of the participants after using the artifact, with user satisfaction questionnaires, or interviews. While experiments is defined as a more controlled setting where experimenters remove variables unrelated to the hypothesis to be tested, to mainly focus on the specific quantitative outputs the researchers are investigating (Sharp et al., 2019). In this master thesis, I chose a usability test, mainly focusing on the qualitative procedures and analysis of the test, but I also used some quantitative data to describe the results. This is described in more details in section: "Research method".

Controlled setting in Lab

As previously mentioned, this usability test evaluated the two different methods of creating the virtual environments for end-users. The end-users in this thesis paper were healthcare workers and therefore, this usability test took place in a controlled setting at the department of simulation at Østfold University College in Fredrikstad city. The centre for simulation is a "practice arena for teaching, interdisciplinary collaboration, skills training, simulation and self-training" (*SimFredrikstad - Høgskolen i Østfold*). Five participants with ranging connections to the healthcare industry such as instructor, student assistant and health professionals. As previously explained, these are participants that are experts within their own field, but does not have any software development skills, fulfilling the role as an end-user. The participants were assigned a group, group one started with the drawing method first, while group two began with camera method first. During the usability test, the users was observed and recorded, to capture the user's reaction in the context of using the different approaches of creating the digital floor plan, followed with a semi-structured interview regarding how the participants felt using the two approaches.

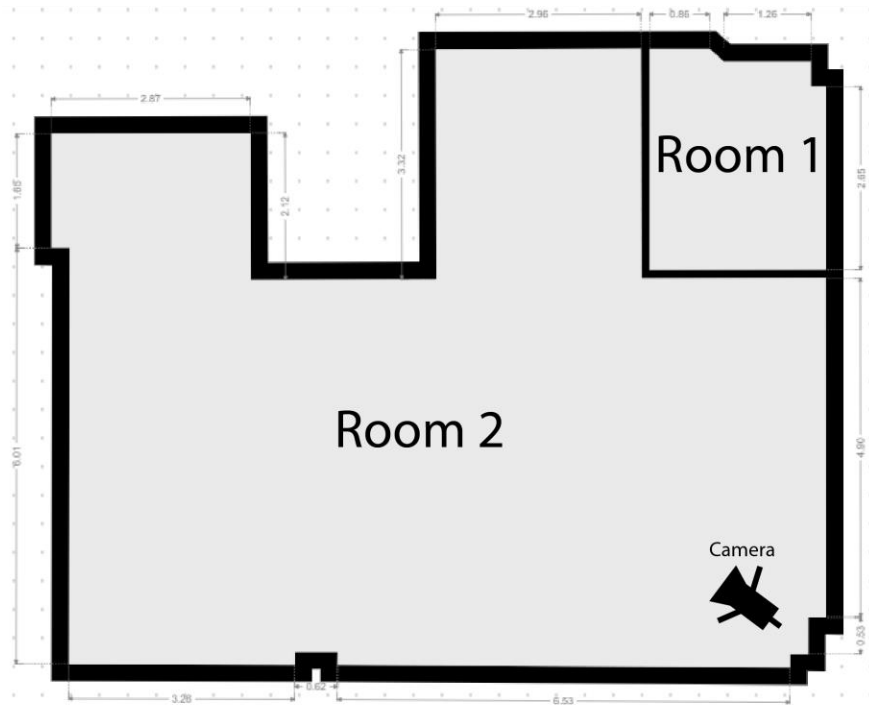

Figure 17 The lab setting

Task briefing

The participants were given a brief explanation of the context of the user-scenario they generated a contribution to. This means explaining that the 3D digital floor plan produced, would in practice be used to create the simulations within. Reason for this, was to produce a sense of importance and understanding to what they aim to achieve in the evaluation, so the participants could understand the use case of such tools. Furthermore, they were given a short explanation of how each method worked before performing the tasks, in terms of how it is used, but not extensively. The participants were also be given a consent form approved by the Norwegian centre for research data (NSD)[8], explaining the goal of this evaluation,

[8] https://www.nsd.no/en

and the necessary information regarding privacy issues, such as the ability to withdraw their contribution, and their anonymity.

The procedures of the usability test

Once the task briefings were completed, the participants had the objective to capture two rooms with the two methods presented to the participant. As previously mentioned, these two methods were specifically used only to capture the measurements and shape of the room, and not objects such as interior, doors or windows. The first room (see Figure 18), was a small room that within room 2 (Figure 17). The participants first performed the end-user creation of the first room with the first method based on the group the participants were placed in as previously explained. Once this was completed, the participants moved on to the next method. Once the participants had captured room 1 using both methods, the next objective was to capture room 2 (see Figure 19) with the same methods in the same order as in room 1. To record the user's reactions and behaviour when using the two different methods, a camera was strapped on top of the head of the participant (a GoPro[9]), and another camera placed within the room (see Figure 17). The cameras position was placed to not obscure the participant's accessibility within the room, as this was important for the usability test, as the tool needs to be used in a natural setting. Simultaneous, I was observing the participant's behaviour and reactions when using the tool by following an observation protocol, which will be further explained below. When both approaches were completed, each floorplan generated by the participant was saved for quantitative measurement of accuracy. The goal of the usability test was to be able to create floorplans as close as possible to the ones seen in Figure 18 and Figure 19. Figure 20 also presents the generated 3D object by MagicPlan based on the floorplan seen in Figure 18 and Figure 19. Furthermore, the participant and I performed a semi-structured interview including ten questions discussing each approach to obtain the qualitative insight for how they felt using the two interfaces, which will also be presented in further details below in section Research method. Lastly, as seen in Figure 18 and Figure 19, there are outline red rectangles to highlight objects that were unmoveable for the user which is important to remember for the results chapter. Additionally, as seen in

[9] https://gopro.com/en/us/

Figure 21, there were number of other furniture and objects such as beds, mannequins and cabinets placed in the room which the users were able to move.

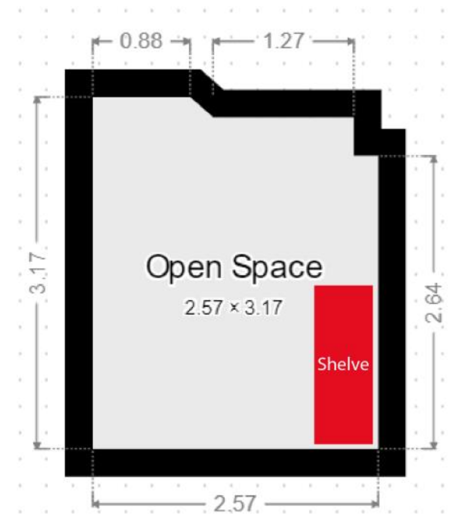

Figure 18 Room 1 floorplan output

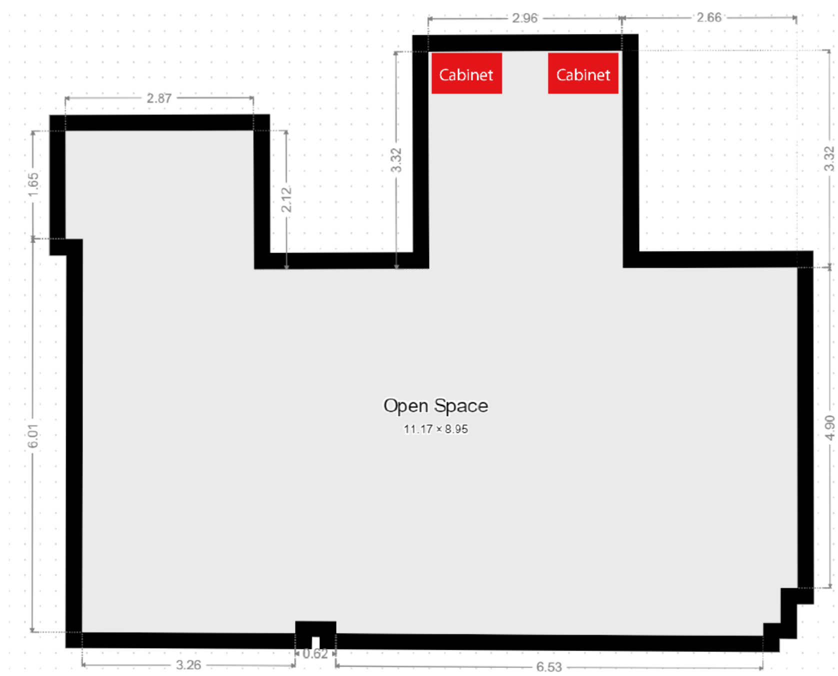

Figure 19 Room 2 floorplan output

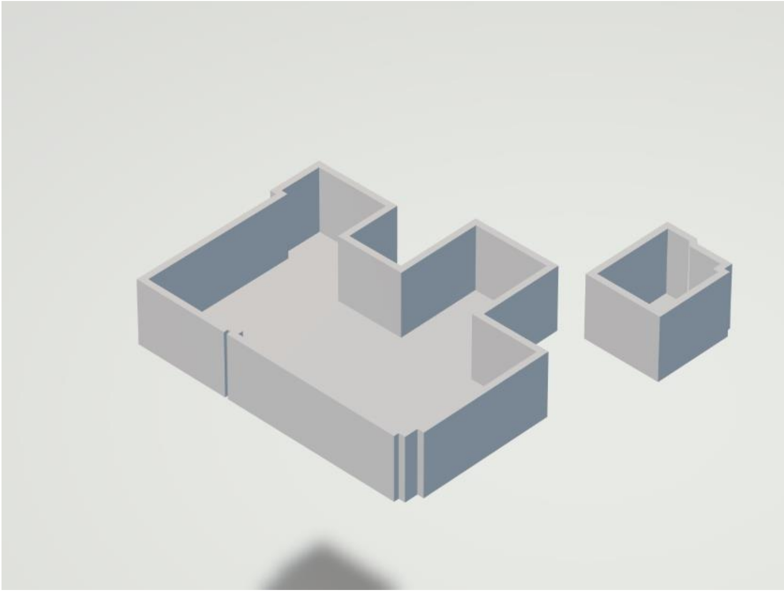

Figure 20 3D generated floorplan

Figure 21 The physical room

2.2 Research method

In this section, I present the current qualitative research design, concerning what qualitative research is, and how the processes of the data collection and data analysis was conducted in this usability test.

2.2.1 Qualitative research design

Silverman (2014), differentiates qualitative and quantitative methods in their definition, by explaining that while quantitative methods aim to answer hypothesis by using accepted statistical measures analysing large amounts of cases often randomly selected. These cases often consist of tables of numbers to be interpreted in the discussion chapter, while in a qualitative method, the aim is to carry out the interpretation throughout the writing, with more focus on specific theory or model the author is using in the qualitative research. Extending, Creswell & Creswell (2017) provide some characteristics for qualitative research such as, researchers usually collect data in the subjects natural field, where the participants experience the issue at hand. Furthermore, the authors explain that the researchers are a key instrument in that they themselves collect the data by examining documents, observing behaviour or interviews. The authors also explain that, in a qualitative research approach, the data collection often gather multiple forms of data, such as the ones named previously above, usually as open-ended forms of data where participants can express their ideas and emotions. To summarize, as Creswell & Creswell mentions, in qualitative research, the goal is to obtain and understand the meanings of the problem held by the participants.

It is also important to establish the procedures for data collection and analysis, to give a clear picture of how this study was conducted. Creswell & Creswell (2017) point out important details that needs to be addressed concerning the data collection procedure, such as explaining where the study takes place, the actors of study, what events occurred and how the processes of these events were performed. To address these first points, as explained previously, the study took place at the centre for simulation at Østfold university college, with me as the observer and interviewee, and participants connected to various areas within healthcare.

Creswell & Creswell (2017) furthermore establishes the importance of clarifying which types of data will be collected and the procedures for how they are collected, such as qualitative observation, qualitative interviews, and qualitative audio-visual and digital materials. There are limitations and advantages to each of these data collection types, for instance, in this study as presented in the design method section, observation and interviews was used as data collection approaches. Few examples of advantages for observations are that researchers will have first-hand experience with the participants, recording of the data can happen in real-time, or observing unusual aspects that may not be observed otherwise. However, a few examples of limitations of observations may be that the researchers can be seen as intrusive, and the ability to be a good observer depends on each person (Creswell & Creswell, 2017). In an observation, it also must be established what roles the participants and researcher have, so for instance in the case of this study, me as the researcher is a complete observer, meaning I observed without participating. However, it is important to note that even though I did not participate in the study, I was still available for questions regarding how to use the interface or other questions that appeared. In an interview however, these options vary from face-to-face in person interviews which was used in this study, to e-mail over internet, focus groups or interview by phone. There are also examples of advantages for interviews, such as participants may add additional information such as historical information, and researchers can control the line of questioning. Examples of limitations are also apparent, such as biases may occur in the presence of the researchers, certain participants may have a hard time articulate the answers well, and data is collected from a designated place not from a natural setting, compared to an observation (Creswell & Creswell, 2017).

Data recording procedures

To record the data consistently, I created a protocol for how the observation and interview should be recorded and collected. In this section I will describe both protocols.

Observation protocol

As described in the design method section, the participant was given the task to attempt to capture and create the physical room they were in, with two different methods using the application MagicPlan. During this, I observed the user behaviour and reactions to using the two different approaches, with an observation protocol. This protocol consisted of a short recording of the participants name and current date, following with two parts, descriptive notes, and reflexive notes. Descriptive notes were notes regarding recording events or activities happening, reconstruction of the physical setting and reconstruction of dialogues. While reflexive notes concerns the researchers ideas, hunches, ideas, problems, impressions and feelings regarding the observation (Creswell & Creswell, 2017). As also previously mentioned, other methods for collecting the data were also done, such as a camera within the room, and a GoPro camera strapped on top of the head of the participant to be later used during the analysis.

Interview protocol

The interview for this study was a semi-structured interview, meaning that the questions were structured, but the participant and the researcher were free to expand on the questions. Furthermore, this interview was guided with an interview protocol consisting of three stages. Before these stages were presented to the participant, the participants name, and date was recorded first.

The first stage, the introduction, the participant was introduced to the goal of the interview and given opportunity to ask or address anything before the interview began. Stage two; the participants was given some basic questions to establish the participant's previous knowledge regarding the topic to be researched. For instance, the participant was asked to rate their own ability to use a smartphone on a Likert scale, and two more questions regarding their previous experiences using smartphones to draw/measure physical rooms.

Once the basic questions were established, the participant was asked three questions for each of the method they used to create the virtual environment, followed with two more questions regarding both methods. Questions regarding each method, aimed to address the participants experience and what they felt using the two methods, for instance, what did you like about the current method? In addition, was there anything that made you frustrated using the current method? Furthermore, the participant was as stated above, given questions regarding both methods. These questions aimed to address which of the methods were most preferable, why the one method was better than the other, and their idea for how to improve the current interfaces.

Lastly stage three, the participants were given questions regarding simulations in their field. Specifically, what previous experiences had the participant with simulations and virtual simulations? Then, did the participant think that the methods for generating virtual environments might be useful in context of end-user development of virtual simulations?

Data analysis procedures

Qualitative data analysis

The data analysis process was based on the suggestions of Creswell & Creswell (2017). The authors suggest that the process of analysing qualitative data is divided into five sequential steps, starting with step one *Organizing and preparing the data for analysis*, step two, *Read or look at all the data*, step three, *start coding all the data*, step four, *generate a description and themes*, and lastly, step five, *Representing the description and themes*.

Starting at step one, all the data for the interviews (audio recording and notes) and the data for observations (observational notes and video recordings), was categorized into each participant. To analyse the video recordings efficiently, I combined the three camera perspectives (video camera, GoPro, and screen recording) into one video, resulting in a video where I could analyse the usability test from multiple angles at the same time. Then the participants were grouped according to their assigned group. Furthermore, all the audio recordings of each interview were transcribed and combined with the notes taken during the interview. Lastly, I created an overview of the output from the participant, by tracing and combining all outputs from the usability test and the ground truth in illustrator. Step two, I reviewed all the data previously organized, to generate and write down ideas and thoughts, such as the general sense of information, and patterns of occurrences. After reviewing the output generated by the participants, I created a score system to measure the accuracy of the input, which is presented more detailed in later sections. Furthermore, after the initial review of the data, I created what I refer to as a breakdown structure, which is also detailed in the section below, and other relevant codes. During step three, I used MAXQDA[10], to code transcriptions of interviews and notes from observations, and the video recordings of the observation. Coding data is the process of labelling sections of the text into categories Creswell & Creswell (2017). Based on step three, I present first in the results chapter the participants task completion timeline with their breakdowns to provide the historical aspects of the tasks, following I analysed and

[10] https://www.maxqda.com/

presented the most often occurring breakdowns and challenges for the participants. Lastly, I presented the scores, and a breakdown review was given.

The breakdown structure and coding

After the initial review of the observation recordings and interview, I discovered the reoccurring scenario of the person seeking assistance when using each method, and similarities with how it was handled. Meaning, for instance a person would have issues with using one of the interfaces, then asking for help, following with the participant progressing based on the input received by me. To be able to categorize these reoccurring scenarios I created what I refer to as the breakdown structure that I present more detailed below. To also record data such as duration of each method and attempts, I created codes that explained which room and which method that was being used by the participant. Other themes such as effectiveness was also discovered when reviewing. The effectiveness themes contain sub-codes such as accuracy/inaccuracy, how the participant was measuring, and good dexterity/bad dexterity. Lastly, feelings such as frustration, confusion, motivation, and trust to the interface was also generated.

The codes

As presented above, the efficiency code contains sub-codes that I generated to label events for how the participant was using the different methods efficiently or inefficiently. These sub-codes are the following: accuracy, inaccuracy, method of measurement, good dexterity / efficiency, and bad dexterity / inefficiency.

Efficiency

- **Accuracy:** This sub-code was used to label events where the participant expressed the need for capturing the room accurate. For instance, was it observed that the participant took their time to measure all the walls of the room as close as the participant could? Did the participant express importance of accuracy or detail? Lastly, did the participant give attention to details in the room?
- **Inaccuracy:** This code is mostly the opposite of the accuracy code, but mostly focused on if the participant disregarded details or quickly estimating the measurements.
- **Method of measurement:** This sub-code was used to detail what methods the participants used to use the interface in terms of capturing the measurements of the room. For instance, how did the

participant estimate the length of the room with the drawing method? Examples such as, using walking distances, estimating by simply guessing, or using reference points. Additionally, how did the participants use the camera method, in terms of, what happens if there are obstacles obscuring the corner points? Does the participant move the obstacle to get closer, or does the participant scan in front of it? Lastly, does the participant get close to each corner point, or does the participant stand mostly still when using the camera method.

- **Good dexterity / efficiency:** This sub-code is mostly used to highlight when a participant can manoeuvre and use the interface efficiently. For instance, do the participants understand how to use the interface to its best capacity?
- **Bad dexterity / inefficiency:** This sub-code is the opposite of the sub-code above.

Feelings

- **Frustration:** does the participant express frustration physically, visually, or verbally?
- **Confusion:** does the participant express confusion physically, visually, or verbally?
- **Motivation:** does the participant motivation frustration physically, visually, or verbally?
- **Trusting:** does the participant express a sense of trust in the interface to do what they want, or do they distrust it?

The breakdown structure

As explained above, the creation of a system to highlight a sequence of events was needed and therefore I decided to go back to the literature to review concepts describing the essential aspect of a breakdown. Once the data has been presented, I will in the discussion chapter discuss my grounded theory to the relevant theory in the literature. This process is what is referred to as an inductive logic of research (Creswell & Creswell, 2017), while in an deductive logic of research, the researcher tests or verifies a theory from the beginning. The breakdown structure is a grounded theory developed based on patterns and categories observed and obtained in the initial analysis of the data gathered during the usability test. This breakdown structure was also created to highlight how often such events occurred during the usage of both methods on both rooms. The breakdown structure consists of the main code, called breakdown, and seven sub-classes.

Breakdown: The duration from the moment the participant, experience a challenge that halts the progress of the task to recovery from said challenge and continue to use the interface as intended.

- **Moment of breakdown:** The moment the problem occurs or the moment the user is not able to perform at an efficient level.
- **Problem recognition:** The moment the participant recognizes the current problem.
- **Seeking guidance:** The moment the participant seeks for guidance to resolve the current challenge at hand.
- **Guidance:** The moment the participant is given guidance according to the problem.
- **Guidance recognition:** The moment the participant understands the logic behind the guidance.
- **Attempt at recovery:** The moment the participants attempt to recover from the challenge.
- **Recovery:** The moment the participant recovers from the challenge.

I also present later in this section an addition to the breakdown structure what I refer to as a "source of breakdown", meaning, what prevented the participant to achieve what they desire. Furthermore, the breakdown structure consists of multiple layers, such as "moment of breakdown" and "problem recognition" is made to describe what happens during the breakdown, how and when does the breakdown occur, or does the participant understand the moment of breakdown. Lastly, the details for how the participants recover from said breakdown also consists of multiple layers, such as "seeking guidance, guidance, guidance recognition, attempt at recovery and recovery".

The breakdown highlighted in the data could contain all the sub-codes, and it could be the case where some of them are not apparent. For instance, a participant could experience a challenge, but before seeking guidance, the participant decided to attempt to recover based on what they think is right. The result of this may be that they learned from the attempt and recovered, or it could also be the case that the participants were seeking guidance after the attempt, or I stepped in and gave the guidance needed. Other examples such as breakdowns where the participants were able to recover with or without the help from me but not necessarily learned from the breakdown could also have occurred.

Source of breakdown: In addition to the breakdown structure, I also created codes to label what the source of the breakdown based on the initial review of the data. Some of the sub-codes are specifically created for each method. These are sub-codes such as:

- **Manoeuvring:** this source of breakdown is usually tied with the "good dexterity", and "bad dexterity", but those are more descriptive labels, whereas this label is to highlight if the source of the breakdown is due to confusion or not understanding how to manoeuvre the interface.
- **[Camera method] initialization of camera:** Is the source of breakdown related to not understanding how to initialize the camera method, or unable to initialize it?
- **[Camera method] setting ceiling height:** Is the source of the breakdown related to not understanding how to set the ceiling height with the camera method?
- **[Camera method] placing and confirming corners:** Is the source of breakdown related to the participant not understanding or unable to place corner points, or confirm the placement of the corner points using the camera method?
- **[Drawing method] placing corners:** Is the source of the breakdown related to the participant unable to placing corner points using the drawing method? For instance, does the participant struggle with getting the program to recognize the user input, or does the participant struggle with placing the corners at the desired location.
- **[Drawing method] adjusting corners:** Is the source of the breakdown related to the participant being unable to adjust the corners at the location where they desire?
- **[Drawing method] Completing drawing:** Is the source of the breakdown related to the participant not being able to complete the drawing by connecting the corner points?

Measuring accuracy

In this usability test it was not expected of the user to be able to complete the task by perfectly measuring the lengths of each wall, and it was also needed a way to quantify how well each person would be able to capture the room using both methods. I therefore decided to develop a scoring system, where the participants could be scored based on how well they were able to capture the room in terms of accuracy. Because it was not expected of the user to be able to capture the room perfectly, I decided that I could score the participants input of each wall based on a certain percentage per method by calculating the standard deviation of each user input for each method. This is described in more detail below, but I will first introduce how the score system is built based on the rooms.

The rooms

The participants could obtain 1 point by capturing the correct measurements of each wall of the rooms, if the participant were to be able to capture the wall within the range of the ground truth + the percentage of the standard deviation, and the ground truth – the standard deviation. For instance, if wall A is 3 meters, and the standard deviation is at 10%, the participant would have a range between 3 meters and 30 cm, and 2 m and 70 cm.

To understand this better, I created the scoring system based on both rooms. So, for room 1, the participant could score a maximum of 8 points, while in room 2, the participant could score a maximum of 20 points. But, if the participant decided that certain walls were not necessary, for instance, wall 4 in Figure 22, contains wall H and F, and if the participant were do decide to only create wall 4 by combining wall H and F, the participant could only score a maximum of 1 point based on the combined length of wall Hand F, losing the opportunity to score a point on wall F and H. If the participants were to correctly measure all lengths of the walls, the participant would score 8 out of a maximum 8 for room 1.

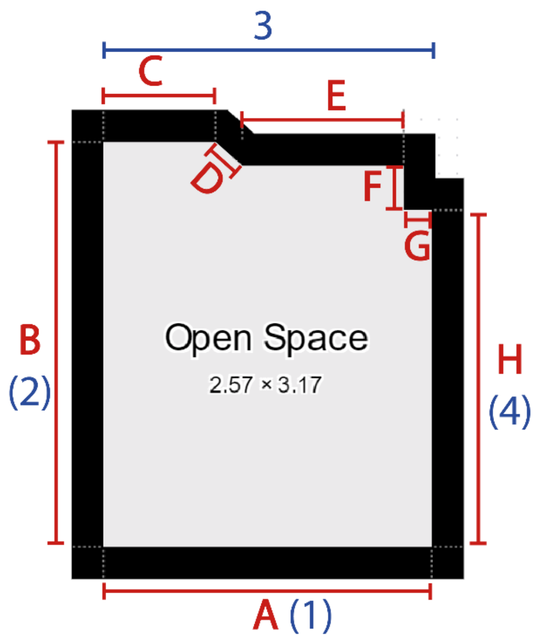

Figure 22 Room 1 scoring system

As explained above, room 2 has the maximum score of 20, applying the same method as room 1. Meaning, the person could also combine certain walls here as well, and still get a few points. So, for instance, a participant could combine wall K and M seen in Figure 23 and get 1 point if the participants measurements were within the range of the combined length of wall M and K, losing the opportunity to obtain 3 points, but only the chance of obtained 1 point instead.

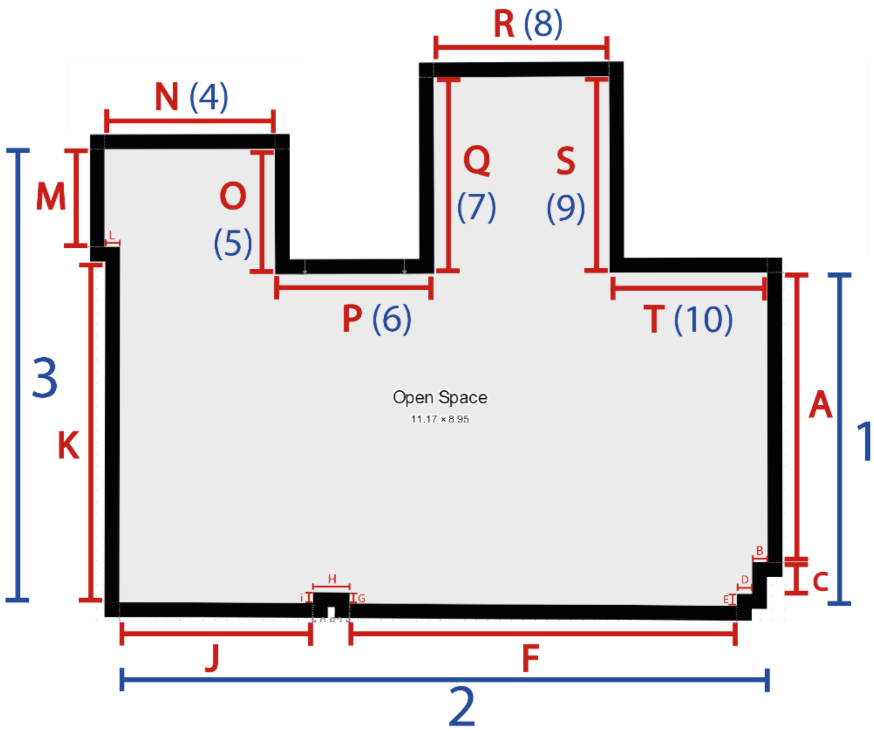

Figure 23 Room 2 scoring system

Calculating the standard deviations

To calculate the standard deviation for each method, I collected all the user inputs, which was obtained from the application and inserted in an excel spreadsheet. Then, I calculated the standard deviation for both methods based on all the user inputs from each wall based on the ground truth. To avoid extreme outliers, I only included the approved attempts, meaning, if a participant would skip a wall like the example explained above with wall K, L and M, I would not include this as an attempt for wall K in the calculation.

Once all the approved attempts were recorded in the spreadsheet, I calculated the difference for each wall compared to the ground truth. Once all these differences were calculated, I created another column that would transform this number to a percentage decimal number. All these numbers were then grouped per method and used to calculate the standard deviation for each method.

To calculate these inputs, I created a python script, and importing the library NumPy[11] used to simply calculate the standard deviation. Once imported the library, I created an array for each method, with all the approved user inputs for each method and used the built-in function in NumPy to calculate the standard deviation.

Reviewing the standard deviations

After I calculated the standard deviation for each of the method, I had two standard deviations presented. For the drawing method, the standard deviation after transforming it to a percentage number was at 59.02% while the camera standard deviation was at 15.71%. At this stage, I wondered why the numbers were so vastly different only to discover that the user inputs of the drawing method had four extreme outliers compared to the rest of the input. Specifically, the inputs were at a minimum of over 200% difference than the ground truth, while the other inputs would vary from a low percentage number such as 3% to a higher number such as 80%. Based on this information, I decided to remove the outliers resulting in a standard deviation of 25.51% instead of original the 59.02% and decided that this difference would be more accurate to the user inputs.

The scoring system

Based on these two standard deviations, I then created the scoring point system explained above. Meaning, that for a wall of a length of 1 meter, the range for the drawing method a participant would get a point from, was within 1 meter and 25 cm, and 75 cm, while with the camera method, a participant would have to measure within 1 meter and 15 cm, and 85 cm. Based on this information, and the score system explained previously for each wall, I created a spreadsheet where all calculations were calculated and then presented in the results chapter.

2.2.2 Reliability and validity

Reliability

Silverman (2014) explain that reliability concerns with how much a study is replicable, meaning how close can other researchers replicate the same results, interpretations and claims. When describing reliability in context of quantitative studies, Silverman explains that reliability refers to the consistency of

[11] https://numpy.org/

results or measurements when repeating the experiment for example. However, this master thesis is a qualitative study, and I will therefore explain in more detail in the lens of qualitative research. Creswell & Creswell (2017) cites Gibbs (2007) when describing qualitative reliability as the indication of how consistent the approaches of the researchers is for other researchers and projects. Silverman explains that Moisander & Valtonen (2006) suggests two options for reliability in non-quantitative research. The first option is to describe the strategy of the research and the data analysis as detailed as possible to provide transparency. While the latter are more concerned about the theoretical transparency in terms of defining the theoretical standpoint to provide insight to how the research produces the interpretations and how they exclude other interpretations. In this master thesis I have attempted to provide as much detailed as possible for the research strategy for how I recorded the data in terms of describing the setting and participants and procedures following protocols presented in the sections above. I have also presented a detailed overview of how I analysed the data produces by the usability test. Meaning, I have provided a detailed explanation for how the data was analysed in context of usability and measuring accuracy.

Validity

Creswell & Creswell (2017) defines qualitative validity as how accurate are the findings of the research by using a set of procedures. Creswell & Creswell recommend discussing relevant strategies from the literature to the data produced in the current study. In this master thesis, I have as explained above in section The breakdown structure and coding explained that the grounded theory used in this thesis is discussed with relevant theories in the discussion chapter. Furthermore, Creswell & Creswell (2017) also recommend to apply multiple strategies for evaluating the accuracy of the data to convince the reader that the data is as accurate as possible. To name a few, methods such as triangulating data, providing rich descriptions and clarifying bias are examples of strategies that can be used. Other strategies also include using external persons to review the findings. It is therefore important to note that in this master thesis, the only researcher to review the findings is myself and my supervisor to some extent. However, in this thesis I have attempted to provide as much details as possible in terms of data triangulation and rich descriptions. For instance, data triangulation revolves around creating themes based on multiple sources of data or perspectives (Creswell & Creswell, 2017). As previously explained, the breakdown structure was created based on multiple sources of data such as observation notes, an initial review of the data using video recordings and from the interviews conducted after the usability tests. Creswell & Creswell (2017) explains that providing rich and thick descriptions of the findings can provide the reader more insight to the events that transpired resulting in a more realistic experience of the data. In this thesis paper, I have attempted to provide as much detail as possible in terms of the events that occurred in the results chapter using the breakdown structure and codes to detail the sequence of events during the usability tests. Additionally, I have also provided an appendix which provides even more detail to the events that occurred.

3 Results

The results presented in this chapter is mostly a generalization of the results presented in the appendix provided in this master's thesis. Therefore, I sometimes refer to the appendix when presenting data in this chapter, and for a more detailed overview of the results, you can read the appendix. As mentioned in the method chapter, and in the appendix, I will present the results from each person in their respective group. Meaning, person one, two and three, are in group one, where they started with the drawing method first, while person four and five, started with the camera method first.

To answer the research question, I will present data what I deem relevant to easy in terms of breakdown and how each participant completed the given tasks, and data relevant to effective in terms of score. First, I will present the completion of the tasks for each person to present the general sense of the tasks performed, then I will provide a detailed presentation of the commonalities in the challenges and breakdowns, to provide an overview of what challenges were most often met by the participants. Following, I will present the comparison of data in terms of completion time, data relevant to the breakdowns, and the score for each person. As mentioned above, this is a "condensed" version of the appendix provided, so I do recommend reading the appendix as well, to read a more detailed description of the completion of the tasks by each person.

3.1 Walkthrough of participants usability tests

I present in this section an abstract recount of each participant's task completion from the usability test to provide insight for how well each of the participants were able to complete the given tasks. A more detailed description of the breakdowns and the recount are provided in the appendix. To clarify, I present each person one by one, with each method following each other. Meaning, for person 1 for instance, I present the result of room 1 and 2 for the drawing method and following with room 1 and 2 for the camera method. However, during the usability test as explained in the methods chapter, the participant created room 1 first with both methods, then moved to the second room with both methods.

3.1.1 Person 1

Drawing method

Room 1

Breakdowns	Placing corner points	Placing corner points and adjusting corners	Placing corner points	Completing drawing	Adjusting corners	Capturing measurements

Table 2 Person 1 room 1 drawing breakdowns

After the participant had been given the explanation for how the interface worked, the participant captured the first corner point, however, confused by the process, the participant tried to drag the first corner, thinking that this was the way to create a corner point. After some help and explanation, the participant seemed to understand the concept and created the first two corner points. However, once reaching the angled wall D, the participant was struggling to place the corner point and adjust it the way she wanted to. After some attempts, the participant decides that this angled wall had to be adjusted later, because she did not understand how to do it. Once the participant had completed wall F and G, the participant attempted to create wall H, but was struggling, because she had created other corner points unwillingly. After some attempts, she understood what had happened, and managed to press the undo button until she could continue. Once reaching the end of the room, she thought she had finished, but I explained that she had to connect the corner points to finish the room, which she proceeded to do. However, once reaching the finalize stage, I mentioned that she could now adjust corner points based on the measurements she could now see for each wall. Before acknowledging that her measurements were incorrect, she wanted to fix the angled wall first. After some attempts, I explicitly explained how she could adjust a corner point, and she had an “a-ha” moment, understanding at this point how this could be achieved. After she was satisfied with how she had “fixed” the angled wall, I once again reminded the participant of the measurements, which she at that time understood was completely wrong. She decided to fix this and started to measure each wall by walking across the room counting the meters. She spent roughly seven minutes at adjusting these corners, but once finished, she was satisfied with the result.

Room 2

Breakdowns	Placing corners	Completing drawing

Table 3 Person 1 room 2 drawing breakdowns

When starting at room 2, the participant was concerned with being accurate from the start and was confused where she should start on the grid, but after some guidance, she was able to begin the task. She began capturing the corner points efficiently, using her walking strategy to capture the lengths of the walls. She did not however, capture some of the details in the lower right corner of the room, and usually recorded each corner points from a zoomed-out perspective. This process was done until she reached the end, where she had to connect the corner points. During this she attempted multiple times to align the corner point on top of the first corner point not realizing that she had to tap the corner point to connect the two corner points. I began to help the participant to connect the corner points, but involuntary created a few extra corners in the process. However, these extra corner points were recognized by the participant and me and was decided not to alter afterwards.

Camera method

Room 1

Breakdowns	Initializing the camera method	Placing corner points	Placing corner points	Placing and confirming corner points	finalizing

Table 4 Person 1 room 1 camera breakdowns

After the initial explanation, the participant struggled to initialize the camera method, but after I had advice the participant to attempt the initialization in room 2, the participant noticed the application was ready to be used and exclaimed “ready to go”. I then explained to the participant that she had to aim at the corners to capture the corner points, but confusingly she aimed at the corner and not on the ground. I then explained that she had to aim it at the ground, and she acknowledged this, and immediately began capturing the first corner points. Once creating the first corner points without hesitation, the participant was confused when the application would not automatically register the corner points for her. After being explained that she could tap the screen, she was able to successfully capture the corner points without any problems. Once reaching wall H, where the shelve is obstructing the view of the corner point, the participant decides to aim towards the corner in front of the shelf recording the corner point. This was later revealed in the finalize stage to influence the result of the floorplan. Once the participant had reached the end and connected the corner points without problems, the participant was able to set the ceiling height with the instructions given by the application. Once reaching the finalize stage, the participant had decided that she wanted to realign the wall H, to which she succeeded, and was satisfied with the result.

Room 2

Breakdowns	Placing and confirming corners

Table 5 Person 1 room 2 camera breakdowns

When given the task to capture room 2 with the camera method, the participant was quick to begin, and started capturing the walls. The participant did however, same with the drawing method, decide not to record all the details of the room. The participant did not experience any problem throughout the capturing of the room however, and was efficient at capturing the corner points, moving all obstacles that was movable, to capturing the corner points up close. However, with the cabinets at wall R, the participant noted that it would not be accurate, as the captured the corner points in front of the cabinet. Even though the capturing had gone well throughout the task, once reaching the end, the participant realised that she had to connect the walls, and in the process of walking towards the last corner, the participant unknowingly had created multiple corner points. Once connected and after she had set the ceiling height, she now noticed the extra corner points. This was recognized by the participant and decided to fix these corner points by realigning the extra corner points, creating one straight wall easily. At this point, the participant was once again satisfied with the result. In the interview afterwards, she pointed out that she probably should have altered wall Q and S to be more accurate in terms of the cabinets obstructing the view of wall R, but at the time she did not.

3.1.2 Person 2

Drawing method

Room 1

Breakdowns	Placing corners and adjusting corners	Capturing scale and adjusting corners

Table 6 Person 2 room 1 drawing breakdowns

After the initial explanation of how to complete the task, the participant seemed to understand the concept and began creating the first wall. However, when reaching the angled wall D, the participant experienced problems with understanding how she could create the angle. The breakdown for this lasted roughly 4 minutes, with me explaining to her how she could zoom in and out to be able to create the corner points more accurately. However, after attempting to create the corner points multiple times, the participant had created many corner points and the participant was confused and frustrated at this point. The undo button only stores a certain amount of undo actions, meaning that she had done so many undesired actions, that she could not undo her work. I asked her if she wanted to restart the task in which she agreed.

Once the participant had decided to reattempt the task, the participant was able to complete the drawing rather quickly, but she was placing the corners rapidly, and it did not look like she focused on creating the corners accurately. Once the participant had reached the finalize stage, she was informed that the measurements of the room could be examined, to which she understood that her measurements were off. At this stage, the participant decided to adjust the corner points to fit the ground truth, but in the process struggling with understanding how this can be achieved. After roughly 2,5 minutes, the participant adjusted the corners accordingly with the guidance of me, explaining to her how she can adjust each corner.

Room 2

Breakdowns	Manoeuvring	Manoeuvring	Placing corner points	Placing corner points	Placing corner points	Placing corners and completing drawing

Table 7 Person 2 room 2 drawing breakdowns

Throughout this task, the participant experienced a series of breakdowns related to how to use the interface efficiently. From the start, the participant did not understand how manoeuvre the interface to move the perspective on the grid. For instance, the participant had problems understanding how to zoom out, and how to move the perspective of the grid. Once she had gotten a better understanding of this, she was able to create a few corner points, before experiencing breakdowns related to placing corner points. These breakdowns reoccurred multiple times throughout the task and was related to the participant struggling to make the application register her inputs as she created corner points by tapping the screen close to existing corners at a zoomed-out perspective. Throughout these breakdowns I informed her how she can recover from this, and she followed the instructions, and successfully recovers often, but she still had the breakdowns reoccur. Once reaching the top left corner of the room, she once again experienced the same breakdown, and at this point, she looked very confused at how she could use the interface efficiently and looked like she had lost track of the shape of the room. Eventually she reaches the end of the room, attempting to connect the corner points to finish the shape, and after a while with the help from me, she finished.

Camera method

Room 1

Breakdowns	Initializing the camera method	Placing and confirming corners

Table 8 Person 2 room 1 camera breakdowns

After the participant had been given the explanation for how to start use the camera method, the participant struggled with initializing the camera method. Not knowing what to do, she asked for guidance, and I advised her to go out to room 2. Once the camera method was initialized, I had to inform her that it was now ready. After I explained that she had to create the corner points by aiming at each corner, she proceeded to as informed, and the application would create the corners for her automatically. However, when this did not happen, she was not sure how to continue, but after I told her that if it does not automatically register a corner, she could manually capture it by tapping the screen. She proceeded to do this but was confused if the corner point had been placed or not. After I explained that it had been captured, she proceeded to capture the rest of the corners and connected them without problems. She even crouched to get the corner that is behind the shelf. Once completed, she explained that she was satisfied with the result, and the participant stated that she now understood that her attempt with the drawing method was probably less accurate.

Room 2

Breakdowns	Placing and confirming corners	Application bug	Placing and confirming corners	Setting ceiling height

Table 9 Person 2 room 2 camera breakdowns

When given the task to capture room 2 with the camera method, the participant faced no problems starting the application and capturing the first corners, but once she had reached a point in the lower right section of the room, the application would not automatically place the corners. The participant was confused at this point, because she had recorded the corner unknowingly, but once I had reminded her that she did in fact capture the corner, she was able to move on. From this point, the participant was moving obstacles and made sure to capture the corner points as accurate as possible, but when reaching halfway through the room, she managed to lock the phone, resulting in the application altering the former corner points. The participant at this point decided to restart.

Once again, the participant did not face any problems with starting the application and began quickly. Until once again, she reached the same location the application would not automatically register previously. This time however, she asked if she could record it herself, to which I replied yes. From this point, she recorded each corner without many problems, and even recorded each corner manually when the application would not do it automatically. Once reaching wall R, the participant decided to record the corner points in front of the cabinets, and this was not addressed later as well. When reaching the set ceiling height stage, she had forgotten what this stage meant, but after guidance from me she was able to complete the task and did not alter any of the measurements done.

3.1.3 person 3

Drawing method

Room 1

Breakdowns	Placing corner points	Placing corner points

Table 10 Person 3 room 1 drawing breakdowns

After the initial explanation of how the interface worked, the participant begins to create the first wall with ease using himself as a reference point to estimate the length of the wall. However, when he attempted to create the second corner point, he wanted to continue from the first corner point he made, which is not possible. At this stage, the participant was confused and created multiple corner points in the process. After some time with assistance, the participant started from the initial breakdown, and once again created the third corner point from the same location. After another breakdown, the participant decides to continue from the second corner point, but at this point he started to create the room upside down. However, from this point he continued to complete task, but he did not create the wall F and G in the process, and he also created the shape of the room mirrored to the ground truth.

Room 2

Breakdowns	Placing corner points	Placing corner points	Placing corner points	Completing drawing

Table 11 Person 3 room 2 drawing breakdowns

The participant began the task by creating wall A without any problems, however, once reaching the detailed lower right corner of the room, the participant experienced a series of breakdowns related to placing corner points. The participants struggle to make the application register his input correctly, but when tapping the screen to record a corner point, the interface targets an existing corner point. I advised him to zoom out and create a corner point further away, then readjust it to the desired location. This breakdown occurs multiple times during this section of the room, but after some time, he began to understand how he could recover from this problem. Once he had recovered, he proceeded to create the rest of the corner points of the room, until he once again experienced the same breakdown at the top left corner of the room. He understood what the problem was at this stage but was not sure how he could recover from it. After some assistance from me, he was able to continue. Once reaching the end, the participants struggled to connect the last corners points together, attempting to align the corner points on top of each other without success. Eventually, he decided to press the exit room button, and the application automatically completed the drawing. He decided not to alter any measurements of the room once reaching the finalize stage.

Camera method

Room 1

Breakdowns	Initializing the camera method

Table 12 Person 3 room 1 camera breakdowns

The participant began to attempt to follow the instructions for the initialization of the camera method without any success. After being advised to attempt to initialize it in room 2 he successfully began. From this point, the participant understood the visual feedback from the camera method and successfully created the corner points without any problems. He even recognized himself that if the application did not automatically place the corner points, he could manually register the corner points himself. Once reaching the set ceiling height stage, he once again followed the instructions without any problems, and successfully completed the room. In the finalize stage, he decided not to alter any measurements.

Room 2

When the participant started the task of capturing room 2 using the camera method, the participant instantly initialized the method, and began capturing the corner points. Even though the participants did not experience any breakdowns throughout the task, he did capture each corner point by standing somewhat from a distance to the corners, and generally trusted the automatically placed corner points. As a result of this, he was quick at capturing the shape of the room, but accuracy did not seem to concern him. Once again, he followed the instructions of the application when setting the ceiling height and successfully completed the task without any problems. Again, in the finalize stage he was satisfied with the result and decided not to alter any measurements.

3.1.4 person 4

Camera method

Room 1

Breakdowns	Initializing the camera method	Understanding the concept	Confirming corners

Table 13 Person 4 room 1 camera breakdowns

When introduced to the camera method, the participant struggled with initializing the camera method for room 1, but after the breakdown was recovered after an exchange between me and the participant, the participant had problems understanding the concept of the method, but just after roughly 30 seconds the participant understood the concept and were able to capture the first walls rather quickly. At this point, the participant had reached the angled wall D, to which the application would not automatically place the corner pieces, confusing the participant. The participant quickly understood a few seconds in after guidance from me that she could tap the screen to record the corner point manually. From this point, the participant was only confused if she should capture the door, but I informed her that this was not necessary, and she was able to complete the capturing and setting the ceiling height without any problems.

Room 2

Breakdowns	Fixing original measurements

Table 14 Person 4 room 2 camera breakdowns

Starting at room 2, the participant began quickly to capture the corner points using the camera method, however, the participant was capturing the corner points from a distance on almost all the corner points of the room quite quickly. Once the participant had reached wall R where the two cabinets are in front of the corner points, the participant were guessing by placing the corner points through the cabinets, placing it at a random location behind. Once reached the finalize stage, the participant noticed that the outcome was not at all what she wanted and were confused at that point wondering what went wrong.

The participant decided to attempt to capture the room once again using the method, and this time she was more aware of where she would place the corner points by walking closer to the corners moving objects that was in the way. For instance, instead of standing roughly 3 meters away from the corner like she did during the first attempt, she would now stand roughly 1 meter away from the corner. During the observation, at this point it all seemed to be going great, and she once again decided to guess the corner points like she did on attempt 1 with the wall R. Once she had entered the finalize stage, the output once again was not how she imagined it to be. Confused at this point, she was spending roughly 9 minutes attempting to fix the measurements of the room.

Drawing method

Room 1

Breakdowns	Adjusting the corners	Understanding the concept	Finalizing the drawing

Table 15 Person 4 room 1 drawing breakdowns

After the participant were explained how the drawing method worked, she seemed to understand the concept, and quickly created the first two corner points, but at that point wanted to adjust the corner point. This was explained, and she proceeded to successfully adjust the corner point. Once she had completed the first wall, she asked if she should repeat this process until she was done, to which I replied yes. She understood from this point that she had to continue and did so. Once she had finished however, she realized she had forgotten to create the corners for wall F and G. The participant proceeded to spend roughly 2 minutes and 40 seconds to fix these missing walls in the finalize stage, finishing the drawing. This participant was also the only one in this usability test to add additional corner points in the finalize stage.

Room 2

Breakdowns	Manoeuvring the interface	Placing corners	Completing drawing

Table 16 Person 4 room 2 drawing breakdowns

Using the drawing method for room 2, the participant quickly began creating the first corners of the room, and once she had reached a position on the drawing requiring her to move the perspective on the grid, she asked how this could be achieved, and guidance were given. From that point, she was standing in the middle of the room capturing all the corner points of the room without many problems until she reached the lower right section of the room, with all the small walls. Here the participant struggled making the application register her inputs, but after guidance she were able to recover and continue. Once reaching the end, where the participant had to complete the drawing, she was confused why the corner points would not connect but completed the drawing with the help from me.

3.1.5 person 5

Camera method

Room 1

Breakdowns	Initializing the camera method	Retrying

Table 17 Person 5 room 1 camera breakdowns

Participant 5 also experienced problems with initializing the camera method, but after the advice to attempt to go outside to room 2 to initialize the camera, the participant was able to start with the method. Once it was initialized, the participant began capturing the first corner points with ease, but from a distance to the corner points. Once she had reached other corners where it was required for her to move, she did move, but noticed that the existing corner points had moved in the process. Even though she was confused by this, she decided to finish, but once reaching the finalize stage, she noticed that the output did was not as expected. After theorizing if her moving would affect the output, she decided to attempt once again.

The second attempt, she stood closer to the corner points, but stood still in the centre of the room. When reaching the corner with the shelves, the participant accepted the automatically placed corner when aiming straight towards the corner through the shelves and finished the task rather quickly without any problems.

Room 2

When capturing room 2, the participant quickly captured the room with the same mind-set as before, to create the corner points from a distance thinking that it could affect the corner points. The participant was recording each corner point rather quickly, putting a lot of trust in the application to capture the corners accurately. When reaching wall R with the cabinets, she made an estimation by placing the corner point behind it without knowing if it was the corner or not. Once reaching the finalize stage, she discovered that some of the walls was skewed, and decided to fix the walls without any problems, and it is obvious that she understands how she can adjust each wall without any problems. One thing to note is that the participant at this point decided to alter almost every corner piece slightly, by estimating the walls after they had been created.

Drawing method

Room 1

Breakdowns	Placing corners

Table 18 Person 5 room 1 drawing breakdowns

After the initial explanation for how the task should be completed, she began adjusting the first corner point at the start of a square without any help and used walking distances to measure the length of the room. She proceeded to record the next corner point and once she had reached the third corner point, which was close to the second, she struggled with making the application register her input. After an exchange between me and the participants, she learned that she had to record it further away and readjust it. This same problem occurred multiple times after as well, but this time she understood how she could recover, and were able to complete the task without any more breakdowns.

Room 2

The participant began capturing room 2 with the drawing method without many problems. At this time, she efficiently manoeuvred the interface, but did experience the same breakdowns experienced in room 1, with the application not recognizing her input. Every time this happened however, she was able to recover by using the same technique learned from room 1. She did not use any techniques to measure the lengths of the walls, but she did however, in the finalize stage decide to adjust a few walls, while estimating the lengths of the walls.

3.2 Common sources of breakdowns and challenges

I present in this section of the result the common sources of breakdowns and challenges that occurred during each usability test to answer the first part of the research questions.

Research question: Which type of user-interface is most beneficial to support the easy and effective end-user creation of virtual 3D environments for virtual task-training in healthcare?

Meaning, that in this section, I will attempt to provide results that will answer how easily each method supported the end-user creation of virtual 3D environments. First, I present the most common breakdowns related to each method, following with the most common challenges for both methods combined, and lastly, I present the participants thoughts about the methods against each other.

3.2.1 Common breakdowns

Drawing method

Placing corners

Placing corners was one of the most occurring sources of breakdowns occurring roughly 16 times across all participants when using the drawing method for both rooms combined. However, this source of breakdown was multi-layered as this source of the breakdown could occur in different scenarios. As explained in the method chapter, to create a wall, the participant had to tap the screen to create a corner point, following with another corner point to create the first wall. This process is repeated until the shape and measurements of the room is completed. However, there were multiple scenarios where the participants had trouble create the corner points.

The first scenario: often occurred when the participant was first introduced to the drawing method. Often would the participants find it challenging to understand that to create a wall, they had to do as described above. Instead, certain participants, like person 1 for instance, attempted to drag the first corner point once placed to the desired location to create the first wall. At this stage, the participants were often confused and were seeking assistance to clarify the confusion, to which I had to remind them of the approach they must do as described above.

The second scenario: that most often occurred was the confusion when the application would not register their desired input. Often the source of this problem was that they would attempt to create a corner point closely to an existing one in a perspective that was either zoomed out too much, or a zoomed in too much, leaving little space for the input to tap the screen, resulting in the application registering the user input as targeting existing corner points close to the desired location. This would often occur at the lower right section of room 2, where the participants had multiple walls closely to each other. This was specifically apparent for person 2, 3 and 4, and sometimes for person 5. Often would the participants fiddle with the interface for a while, attempting to create the corner point by tapping the screen multiple times but without successfully adding the corner points. At this stage, the participants would often be confused or frustrated to why the application would not register the desired input and would often seek assistance from me. Person 3 even stated in the interview that he would find the drawing method suboptimal due to this breakdown. Person 5 also expressed that she wished that she could somehow lock existing corners to their positions, as she sometimes experienced that she moved existing corner points unwillingly. I would usually respond with explaining that they should try to place the corner point further away from the existing corner points then adjust it to where the desired location would be. Often would the participant respond with successfully following the advice, but also often have the same problem occur just a few seconds or minutes later, and the breakdown would repeat itself. However, after a few times, the participant would learn from the mistake, unlike person 5, who quickly learned how to avoid this breakdown. However, person 1 never experience this specific problem, but as noted previously, person 1 was also the only one not creating the smaller details in the lower right section of room 2, where the breakdown would most often occur. However, it would often be the case that smaller walls often encountered in the start would not appear again, leaving more room for the user to create corner points on.

Adjusting corners

This source of breakdown was also related to placing corners, but sometimes it would be the case where a participant would have problems with creating a wall that required the participant to adjust a corner point. This source of breakdown would also often have a relation to the second scenario of the breakdown "placing corners" with the drawing method, as it often would require the participant to adjust the corner to recover from the breakdown. For instance, person 1 experienced that for her to create the angled wall D in room 1, she had to adjust the corner point, but she never understood how this could be achieved until she was explicitly told during the finalize stage how it was achieved. This exact scenario also happened for person 2, where the participant would decide to not adjust the corner until they had entered the finalize stage. However, neither of these participants at the time knew that a finalize stage would come, therefore, they had accepted up until that point that they would not be able to create the angled wall.

Completing drawing

Another common source of breakdown when using the drawing method was completing the drawing. The general idea is to align the last corner piece with the first corner piece, then tap the first corner piece to connect the two. However, person 1, 3 and 4 all experienced the same problem when attempting to complete the drawing for room 2. All three-participants attempted to place the last corner point on top of the first by adjusting the corner point as close as possible, but nothing happened at this point. At the time, I was not sure how this worked myself, so I recommended all the participant to align it as close as possible, then exit the room, making the application automatically connect the two. What I should have informed them of, is that they only had to tap the first corner point, as all the participants had successfully done in room 1.

Camera method

Initializing the camera method

A common breakdown occurrence was the initialization of the camera method. As explained in the methods chapter, at this stage of the camera method, the participant had to provide the application insight in the scale of the room for it to accurate capture the room. Of the five participants, all five participants had this breakdown problem occur in room 1, but never in room 2. Not only did all five participants have this source of breakdown occur, but it was also recovered the same way for each participant.

For instance, when each of the participants were explained that to begin, the camera must be initialized, and to achieve this, they would have to follow the instructions given by the application. Each of the participants mostly followed these instructions during the task in room 1, but none of the times would the application initialize. From this point the participant would either continue to follow the instructions, or they would seek guidance. Then I would every time advise them to walk out to room 2, and attempt to start the method from there. This advice was followed by all the participant and all the participants succeeded at initializing the camera. When the task was given to capture room 2 however, the application would always almost automatically initialize quickly.

Placing corner points and confirming

Most of the participants was quick to realize how they should capture the corner points using the camera method, as the interface gave an indication if the corner point had been captured. For instance, person 1 mentioned during the interview that the interface gave visual cues when a corner point had been captured. But once the camera method did not automatically capture the corner points, many of the participants were confused as to why that was. Person 1, 2, and 4 was examples of this. Most of the times the participant would express confusion to why it would not register, but after a brief explanation that they could manually register by tapping the screen, persons 1 and 4 would instantly understand this process and move on. However, person 2 would experience this issue multiple times asking me if she should tap the screen, or she was unaware that she had tapped the screen. Person 3 and 5 however, understood this by themselves without the guidance from me, and were able to efficiently use the interface from the start. Another thing to note, person 1 for example experienced that she would at the end of room 2 create corner points without being aware as she moved towards the last corner point, and once entered the finalize stage she would recognize it and had to fix it.

3.2.2 Common challenges of methods

Accuracy

Challenges such as accuracy was also apparent during each method. For instance, how a participant would estimate the walls, and how obstacles would affect the accuracy of the measurements.

Method of measuring

The camera method itself would somewhat capture the length of the room because of its augmented reality approach where the participant could place the corner points at the specific locations, but the drawing method does not include any measurement tools besides one square on the grid being one meter in real life and the finalize stage where the participants could see the measurements they had generated. It was only observed by two participants the use of walking distances to measure the lengths of the room when using the drawing method. It is unclear what other methods the participants used to estimate the lengths of the room, but for instance, person 3 expressed during the capturing of room 1, that he would estimate the length of one of the walls based on his own length, using himself as a reference point. Even though two participants were observed to measure the lengths of the walls using walking distances, only person 1 was using this method consistently.

During the interview, the problem of not being able to capture the lengths using the drawing method was also emphasized by the participants. For instance, person 5 expressed that if she would have the measurements beforehand, she would be able to produce a more accurate output. Person three also expressed that he would find the drawing method unsuitable because the lack of understanding if his measurements were correct or not. He also proceeded to express that the camera method made him also more confident in capturing the room as he did not have to worry about if the measurements were correct or not. While participant four also expressed during the interview that a substitute for the drawing method to capture the lengths of the room would be of good use.

Obstacles obscuring corners

In specifically room 2 but also in room 1, there were obstacles obscuring the vision of the corners that would affect the way each participant would capture each corner. For instance, in room 2 there was a couch and other movable objects to which most of the participants would move to reach the corner points. For instance, persons 1, 2 and 4 would often move objects to capture the corner up close, while persons 3 and 5 would often trust the applications ability to capture the corners by aiming in front of the application. However, the cabinets at wall R would often be a challenge for most of the participants. Person 4, 5 would attempt to guess the location by manually creating the corners through the cabinets, which in result for specifically person 4 would end up with walls way longer than the participant thought, and it also affected the shape of the room, by which she had to fix in the finalize stage. While persons 1, 2 and 3 would scan the corners in front of the cabinets. Person 1 would also point out this as a potential problem for the sake of accuracy, but neither of the participants would readjust this section in the finalize stage.

3.2.3 Drawing method vs Camera method

When asked which method the participants preferred in terms of ease of use during the interview, all participants except for person 4 choose the camera method for various reasons. Person 1 stated that she felt the likeliness for error was less when using the camera method, because the application would handle the measurements. Summarized, person 1 said: "Firstly, I found the interface logical, secondly I felt a sense of mastery and thirdly, I trusted it". She did however mention that, if it were not for the fact that she had used the drawing method beforehand, she would perhaps struggle during the finalize stage. Person 3 stated that he would choose the camera method because he felt it was more accurate than the drawing method, and because he did not need to concern himself over if his measurements were correct or not. Person 5 however mentioned that even though she believed that the camera method would initially have worse accuracy, she believed that it was a faster method to obtain the initial shape of the room, and then she could adjust it according to the real measurements. On the contrary, person 4 mentioned the opposite, stating that she had better control using the drawing method, and less adjustments had to be made afterwards.

3.3 Score and breakdown review

As previously explained, I will in this section present the data related to answering the second part of the research question, meaning the effectiveness of end-user creation of virtual 3D environments.

Research question: Which type of user-interface is most beneficial to support the easy and effective end-user creation of virtual 3D environments for virtual task-training in healthcare?

Therefore, I will in this section present data regarding breakdowns and score of each attempt with room one first, then room two following. This data is the simplified version of the data presented in the appendix, therefore some information will stay the same, while other sections will remain simplified. In both room sections of this section of the results, I will first present the data regarding the completion time and breakdowns, then secondly, present the data regarding the score. One thing to note is that, as explained in the methods chapter, the score is based on the standard deviation for each method, and therefore the comparison will only be displayed for how well each method performed in the context of their own method. Lastly, I will summarize the data for both methods and both rooms combined.

3.3.1 Room 1

In Figure 24, is a quick overview of the output each person made compared to the ground truth, with the green outline of the room is the ground truth, the red outline is the draw method output, and the blue outline being the camera method output. There are also a yellow outline highlighting the first attempt a user had if it were to be the case that a participant used more than one attempt. This colour is used for both methods.

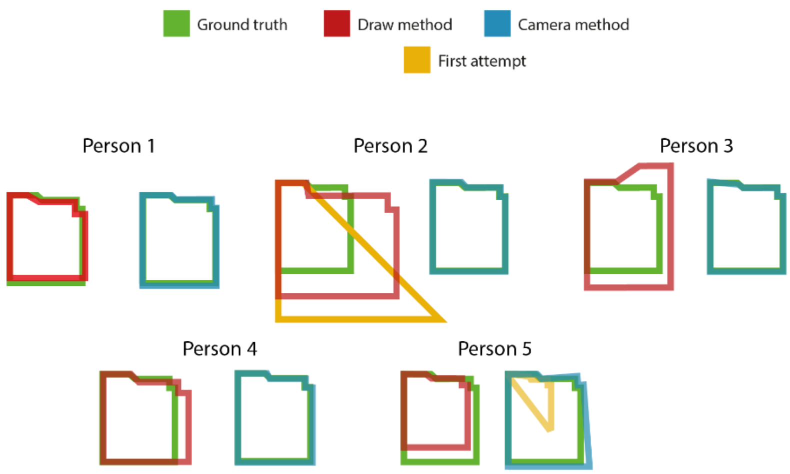

Figure 24 Room 1 output comparison

Breakdowns and completion time

As explained in the appendix, by examining Table 19, the combined difference in time spent per method is 16 minutes and 44 seconds, with the drawing method using 35 minutes and 30 seconds, while the camera method was at 18 minutes and 46 seconds. Even though in totality the drawing method spent 16 minutes longer, it is worth pointing out that participant 1 spent a considerably longer time to complete room 1 using the drawing method than the rest. However, this will be further explained below. Another thing to point out, which is explained in the appendix is the fact that both methods had 1 extra attempt, from two different participants.

Room 1	Drawing	Camera
Total attempts	6	6
Total time spent	35m 30s	18m 46s
Average time spent	7m 06s	3m 45s
Total number of breakdowns	14	13
Average number of breakdowns	2,8	2,6
Total time spent on breakdowns	25m 35s	7m 34s
Total average breakdown duration	5m 07s	1m 30s
Average breakdown duration	1m 49s	34s

Table 19 Room 1 completion and breakdowns summary

Even though the number of breakdowns is only 1 more with the drawing method (14 breakdowns) than the camera method (13 breakdowns), the total time spent and average duration per breakdown is noticeably different (see Table 19). For instance, the total time spent on breakdowns with the drawing method is at 25 minutes while with the camera method it is at 7 minutes. But, as previously explained, this might be the case because of person 1 spending a total of 15 minutes herself on breakdowns during room 1 with the drawing method. However, when inspecting the average breakdown duration, the drawing method is at 1 minute and 49 seconds while the camera method is at 34 seconds.

Score

In Figure 25, a graph of the current scores achieved for each method for room 1 is presented. A more detailed version is presented in the appendix. In the graph, the max total score of 40 points is outlined in blue with the total score of all participants outlined in orange. Out of the 40 total points, the drawing method scored a total of 22 points, while the camera method scored a total of 36 point (see Table 47). Furthermore, the max score per person at 8 points and the average score per person is outlined in grey, with the average score (outlined in yellow) at 4.4 points using the drawing method, while using the camera method, it is at 7.2 points (see Table 47).

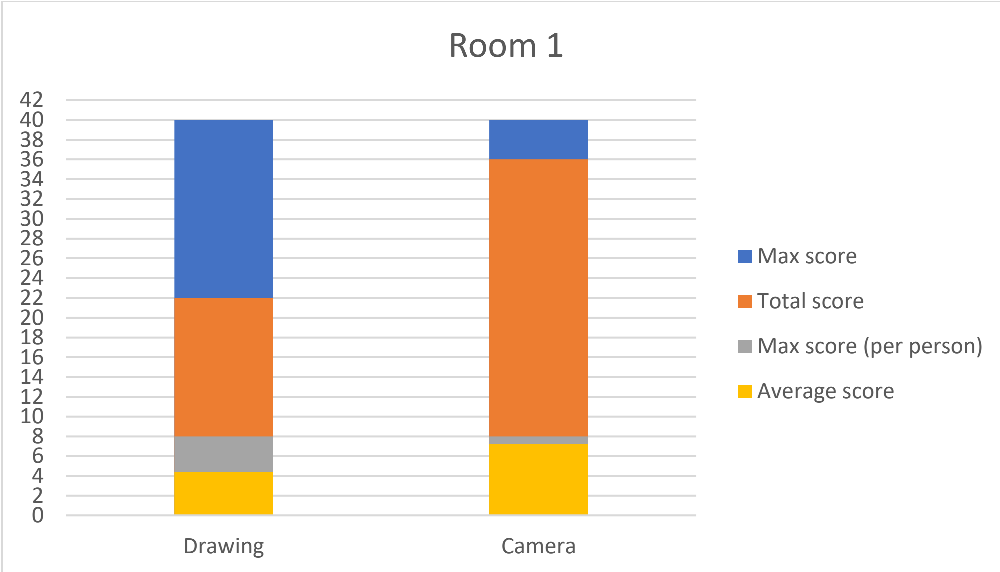

Figure 25 Room 1 score overview

3.3.2 Room 2

Like Figure 24, Figure 26 also highlight the individual outputs of each method compared to the ground truth, using the same colour code to the outlines as previous. With green being the ground truth, red being the drawing method, while blue is the camera method, and as previously, the yellow outline is for the first attempt of the user used for both methods.

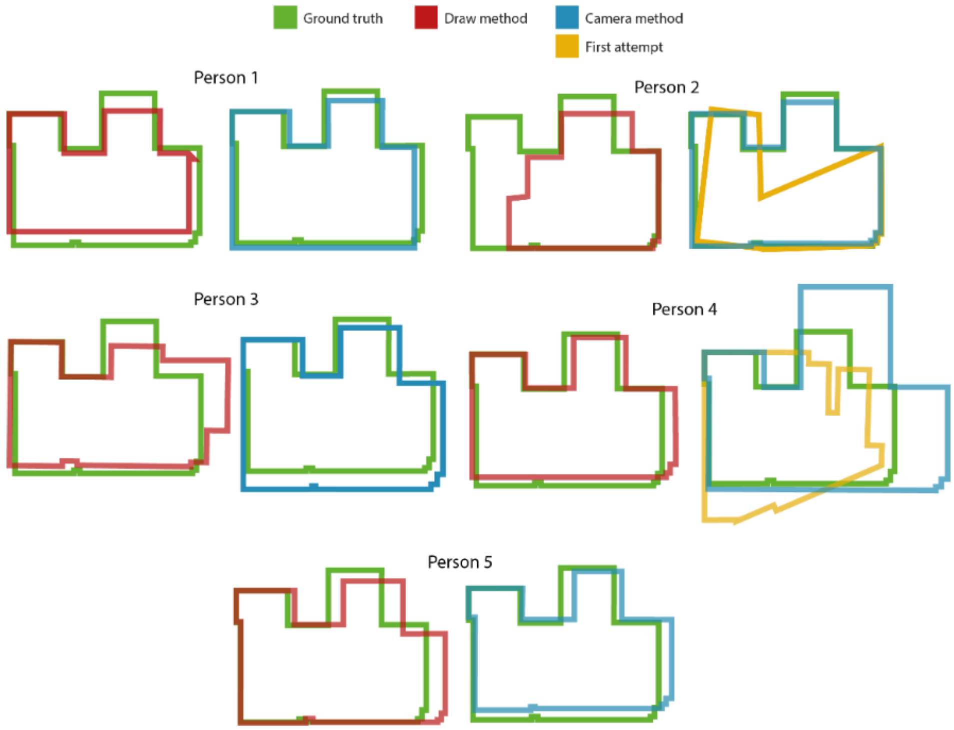

Figure 26 Room 2 output comparison

Breakdowns and completion time

In terms of completion time, both methods used 47 minutes in total each, with only 14 seconds longer with the camera method. The total average time spent on each method is also very similar, with the drawing method using 9 minutes and 27 seconds, while the camera method using 9 minutes and 30 seconds (see Table 20). Furthermore, the drawing method only required one attempt on all participants, while the camera method required two attempts on two participants.

Room 2	Drawing	Camera
Total attempts	5	7
Total time spent	47m 18s	47m 32s
Average time spent	9m 27s	9m 30s
Total number of breakdowns	15	8
Average number of breakdowns	3	1,6
Total time spent on breakdowns	14m 54s	17m 37s

Total average breakdown duration	2m 58s	3m 31s
Average breakdown duration	59s	2m 24s

Table 20 Room 2 completion and breakdowns summary

The number of breakdowns is more divided in room two, than room one, as the drawing method had 15 breakdowns, while the camera method only experienced 8 breakdowns. However, the total time spent on all breakdowns combined per method is shorter on the drawing method than the camera method, separating them with 2 minutes and 43 seconds. Additionally, the average breakdown duration is at 59 seconds when using the drawing method, while 2 minutes and 24 seconds using the camera method. Another thing to note is that two participants experienced zero breakdowns with the camera method, and one of these participants are person 5, which also did not experience any breakdowns with the drawing method as well (see Table 20).

Score

Like Figure 25, Figure 27 also show the max total score achievable by for each method presented in the graph. In room 2, the drawing method scored a total of 53 points, while the camera scored a total of 52 points (see Table 52). Additionally, the max score an individual could score was maximum 20 points, and the average score was at 10.6 with the drawing method and 10.4 with the camera method (see Table 52).

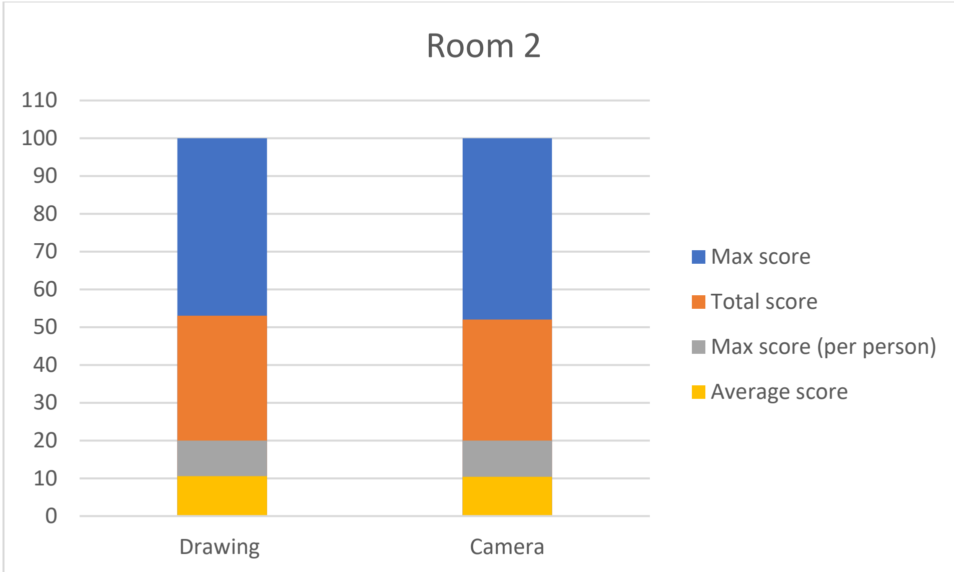

Figure 27 Room 2 score overview

However, as presented in the appendix, person 5 was the only one to score a score above 15 using the drawing method scoring at 18 points, while the highest point achieved with the camera method was at 13 points, scored by the same individual and person 2.

3.4 Domain experiences of virtual and non-virtual simulations for task training

The participants were intrigued of what the effects of this study might lead to. For instance, when asked if the participants had any prior experience using virtual simulations for training before, a variety of answers were given. For instance, person 1 discussed VR simulations for drug management. Person 3 mentioned that he had prior experience with a simulation in which the user would see a virtual body to interact with and another experience with using simulations to investigate how to interact with a patient in which he as a user could see a variety of numbers and measurement. He also mentions that these simulations gave insight for how it is within medical office without being there. Person 4 mentioned that she only had prior experience in physical simulations, however when asked if she believed virtual simulations to be beneficial, she stated yes, and such simulations could be beneficial in all domains and all aspects of life, as she believes simulations could prepare individuals to situations never experienced before. Person 5 also had a variety of prior experience using virtual simulations ranging from VR serious games, to pre-recorded physical simulations where the participant acts as a passive observer using camera technology to capture multiple perspectives during an operation. Person 2 however mentioned that she did not have much experience using virtual simulations, and therefore had problems understanding what the benefits of this study would be. However, when the rest of the participants were asked if they believed it to be any benefits if they as the end-user could create virtual simulations themselves and specifically if they believed either of the two approaches to capture the environment could be a possible solution, multiple positive feedback was given. For instance, person 1 stated that her prior experience with virtual simulations is often very expensive, specifying that it is usually the software that is expensive and not the hardware. She continues to highlight the fact that she believes it to be very beneficial to create these simulations themselves with this context. Person 3 stated that he saw the benefits in terms of learning from home, especially now in the context of covid-19. Person 4 also stated that it could be beneficial in terms of location. However, in her case, she stated that in her workplace, "physical simulations often become a one-day thing, having to rent a location and we have to make it a big thing. Instead, we could use a staff meeting room and make it a more a daily routine". Person 5 however stated that it all was depended on what types of simulations that was supposed to be made, but in terms of animated simulations she believed that the approaches used in the usability test should be sufficient. However, she also stated it would be depended on how one would also have to decorate the room with standard furniture such as hospital beds etc.

4 Discussion

In this chapter, I discuss the relevant theory of breakdowns in context of the breakdown structure used in this thesis paper, followed with a discussion for which type of interface could be most beneficial for end-users based on the implications of the breakdowns. Furthermore, I discuss the benefits and challenges of the interfaces tested in this thesis in the context of end-user development and tailorability of virtual 3D environments and simulations. Lastly, I discuss the societal contributions an end-user development tool like this could potentially provide.

4.1 The breakdown structure and its implications

4.1.1 The breakdown structure and theory

During the analysis as explained in the methods chapter, I had to define a framework to analyse and categorise the data from the usability test. The breakdown structure was a result of this, which consisted of describing the sequence of events that occurred, specifically the events that prevented the participant from continuing with the task at hand. Based on this I decided to do a review of the literature related to breakdowns and discuss my findings with the literature.

Svanæs (2013), explains the idea of a tools readiness based on the book "Understanding Computers and Cognition: A New Foundation for Design" written by Winograd & Flores (1986). Svanæs explains that Winograd & Flores, based on the book "Being and Time" (Heidegger, 1927), argue that a computer is a tool, and it is transparent at use for the skilled users, and is described as "ready-to-hand". Svanæs continues with describing a scenario, where him as a user would use a text editor (the tool) to write a paper, focusing on the content of the text and not the tool he is using (ready-to-hand). However, if the tool would crash, his focus would be redirected to the tool itself. This scenario is what is described as a breakdown scenario, and Svanæs goes on to say: "the computer stops working as a tool and emerges as an object in the world". This scenario of the tool "emerging as an object in the world" is what is referred to as "present-at-hand" by Winograd & Flores (1986). The definition of the breakdown fits well with what experienced during this master thesis, as most of the breakdowns were in the context of "ready-to-hand" to "present-at-hand". For instance, the common occurrence of placing a corner point using the drawing method started first as an objective of capturing the corner points using the tool (ready-to-hand), but early on and when more challenging and detailed corners appeared, some of the participants struggled with using the interface efficiently and not understanding how to navigate it. At this point, the participants would often change their focus from the task to understanding and learning how to navigate the interface (present-at-hand). Winograd & Flores (1986) explain that a breakdown is not necessarily a negative situation, but instead, it reveals central aspects for what is required to understand for accomplishing a given task using the tool. In this case, what was discovered was that using a breakdown structure as an analytical framework, I could identify which of the two approaches contained most breakdowns, and to what extent the breakdowns for each approach impacted the task at hand (see section The drawing method vs the camera method).

Similarly, A. I. Mørch (2020) operationalized a model he refer to as "the Action-breakdown-repair model (ABR)" based on the works of Winograd & Flores (1986), but also from (Ehn, 1988; Fischer, 1994; Schön, 1983). In Mørchs study, the author used the ABR-model as an analytical framework to provide insight for how students could learn domain knowledge and technology using Minecraft and Second life as an engaging tool for students to participate in learning. In this study, Mørch would use the first stage of the model: action as a way of describing what the participant aimed to achieve, the second stage, the breakdown: to describe where in the process of action would the participant halt and be unsure how to move on. Following with repair, meaning, how did the participant learn or move on from the breakdown. In the breakdown structure I provide more layers of "insight", for instance, if we were to compare (see Table 21), starting at "action", I created the label source of breakdown. Even though this label describes what the intended action was, it does not necessarily provide the same context as "action" would do. Moreover, the breakdown is also slightly similar, the breakdown label in the ABR model provides a description of what the breakdown is and what prevents the participant from continuing the task, while, in the breakdown structure, I attempted to provide more insight to the moment of when the breakdown occurs and if the participant recognized the problem causing the breakdown. Furthermore, in the repair stage of Mørchs ABR model, I had a more layered description of how the participant recovered from the breakdown. Mørch uses a general description of the recovery, while I attempt in the breakdown structure to provide the historical sequence of events by providing specific descriptions of the events that occurred.

ABR model		
Action	Breakdown	Repair
Breakdown structure		
Source of breakdown	Moment of breakdown and problem recognition	Seeking guidance, guidance, guidance recognition, attempt at recovery and recovery.

Table 21 ABR model and Breakdown structure

Even though it would seem to be the case that the breakdown structure provides more detail to the events that occurred, I believe I could have operationalized it better in terms of providing the insight, whereas the ABR model provides a more general sense of the events that occurred. However, it is still interesting to note the similarities between the results.

4.1.2 The drawing method vs the camera method

When comparing the two given methods for end-user creation of virtual 3D environments, a variety of challenges for each method was apparent. For instance, in the context of the research question, what type of interface, and in this case, which of the two interfaces was deemed most easy to use and adopt, and which of the two were the most effective in terms of accuracy and time spent per method. These are all aspects I discuss in this section.

First addressing the initial adoption of each method, when given the camera method to complete the given task, then the results seemed to indicate that the camera method was not only the quickest method to be initially adopted by the participants, but also the most accurate in room 1. At this time, the participant was given a brief explanation as possible, to understand which method was the easiest to pick up. One thing to note is that the results could potentially have been affected due to the brief explanation given during the usability test, and therefore it would have been interesting to see what the results would be if I had given a more thorough explanations from the start. However, when the participants were given the camera method, as stated in the result, it was hard for all the participants to understand how to initialize the camera method, but it was quickly resolved by the advice to go out to room two. One thing to note however, this seemed the fault of the application itself, and not a result of how each participant would follow the instructions of the application because the method would almost instantly initialize when provided a larger room. I also tried to initialize the camera method myself in room 1 without succeeding to make sure. Furthermore, the result showcase that almost all participants were able to understand how to create the first corner points without much assistance. I believe this could have something to do with the fact that the participants would see the room through the camera and better feedback given from the application through the augmented reality interface, and therefore possibly understand the concept better. For instance, participant 1 would state something close to this: “when I see the room through the camera and got the feedback when I pointed the camera towards the corners it was firstly, very logical for me, secondly, it gave a feeling of mastering and thirdly, I trusted it". Unlike the camera method, the drawing method seemed to have a steeper learning curve, as the participants struggled more with initially understanding the concept of creating the walls. Looking at the results the participants would spend a lot of time and often have breakdowns occur in the context of understanding the concept. Not only would the participants have to understand how to navigate the interface, but they would also have to understand the concept in terms of how to create the walls, and how to adjust them accordingly unlike the camera method, which only requires the participant to place them. For instance, once the participants had understood the basic concept, two of the participants (person 1 and 3) struggled with creating the angled wall initially because they did not know how to adjust the corner points and struggled for a while to learn how to achieve the desired action. The result of this was initially to move past it, and let it be, but during the finalize stage they got more instructions and were willing to fix this issue once they understood how. The results seem to support the idea that it was easier to overcome the breakdowns with the camera method compared to the drawing method during room 1 when inspecting Table 19. For instance, even though the number of breakdowns were slightly similar, the total time spent on the task and during each breakdown on average and total time is different indicating that the breakdowns were easier to recover in the camera method than the drawing method. Additionally, it would also seem to be the case that the camera method would score in total and on average better than the drawing method with a less percentage of standard deviation, meaning less room for error (see Figure 25). For instance, with the camera method all the participants were able to score at least 6 points or higher out of a maximum of 8, while with the drawing method however, only two of the five participants were able to score above 6. One interesting thing to note is the fact that these two people were the participants placed in group two, meaning the drawing method was the second method they would use to capture the room.

However, shifting focus to room 2 with more advanced room geometry, the results indicated a somewhat equivalent result as both methods used scored slightly similar and time spent per method was also similar. However, this may be due to multiple factors. For instance, when using the camera method, two participants required to restart the task. Person 2 was due to application bugs as she managed to close the application, and therefore experiencing breakdowns related to this, and more time elapsed. While person 4 had to retry the task due to not understanding why her output was visibly wrong the first time. Using the camera method, different approaches to capture the corner points seemed to affect the results somewhat. For instance, in room 2 more obstacles and room geometry could have potentially affected how each participant would perceive the accuracy of the method, with some of the participants would rely on how well the camera method could capture the corner points, by standing from a distance, or guessing the corner points by scanning the corner in front of obstacles, while other participants would stand closer and more focused on capturing the exact corner. This challenge also support the hypothesis of (Sankar & Seitz, 2012) that obstacles could in fact affect the accuracy of MagicPlans AR approach. This is especially true for wall R where the cabinets were unmovable, making the participant decide to either scan in front or guess the location through the obstacles. While, with the drawing method, the participants would often struggle when creating the details in the lower right section of the room, which most of the breakdowns would occur and more focus on learning how to navigate and create new corner points would once again arise. Judging by these facts, the participants did not experience any problem in creating the corner points using the camera method, while the drawing method would still be a focus for the participants indicating that the camera method was the more user-friendly choice, and even when asked during the interview, most of the participants would state that they preferred the camera method. This is also supported by the fact that by adding the number of events the participant required guidance when attempting to specifically create corner points with both methods were higher with the drawing method than the camera method. Specifically, when looking at the results appendix, in total the drawing method required 20 guidance's in total while the drawing method only required 9.

4.2 End-user development of virtual simulations

Even though during this study, it might not be necessarily conclude which of the two interfaces were most beneficial for end-user creation and tailoring of virtual 3D environments even though based on the results the camera method seem to be the most fitting, the results are promising by the fact that the participants less than 1 hour without any prior experience in 3D modelling which fits the description of an end-user by Nardi (1993), managed to in practice to capture and 3D model two existing rooms two times using two different interfaces. It is important to note that the goal of this usability test was to capture already existing physical rooms, and therefore if it were the case that the end-user would want to create a room based on imagination, the camera method would not be suitable. However, since only five participants were participating during the usability test, I can only make assumptions, but judging by these results, I believe with proper training on how to use the methods or more time using the methods by themselves, these two methods separately or combined allows end-users to take the first step at capturing and creating virtual 3D environments and simulations to the context of their use. To put this in perspective, creating similar 3D environments using professional tools such as AutoCAD, SketchUp pro or other CAD-software, requires professional knowledge and skills (Santos et al., 2011). The catch of these methods is the fact that the tailorability these methods provide is limited. With 3D modelling tools such as the ones mentioned, more functionalities open the availability to enrichen the environment with more details such as extruding walls, refining corners and more options in terms of rendering a more realistic environment. This is the classic example of finding the balance between the “Turing-tar pit” and “inverse Turing tar pit” (Fischer & Giaccardi, 2006) as the professional tools provide the functionalities to recreate a room almost identical to the physical ones but the functionalities utilized are more difficult to perform, while the methods used in this thesis only provide a certain amount of details to recreate existing rooms. Additionally, this study has primarily focused on only the two rooms’ basic room geometry, and therefore I cannot say for a certainty say how well these approaches would perform under circumstances where advanced geometry would be more apparent. These two methods mostly provide the tools to create the initial shape of the room, using basic walls with minor amounts of details, such as windows and doors. Even though MagicPlan provides options to place windows and doors which would enrichen the environments even more, I have as previously stated only focused on investigating which of the two methods would be most beneficial for capturing the room in the first place. However, I have in this master thesis provided a detailed description of the usability of the two methods the papers presented in related work has not addressed. For instance, both Santos et al. (2011) and Vosinakis et al (2007) present a tool for generating rooms based on 2D floorplans which the drawing method in this master thesis addresses. In hindsight I probably should have considered using existing floorplan images the end-users could use to draw on top with the drawing method which Santos et al. (2011) used in their paper as MagicPlan also allows for inserting floorplan images. I believe this could have affected the results of the drawing method since most of the participants would state that they had trouble using the drawing method because they found it difficult to capture the initial measurements correctly. Additionally, it could possibly also have affected how the participants would perceive and understand how to use the interface. Furthermore, I have also addressed the usability of the camera method, while as presented in the related work, approaches similar to the camera method such as Rosser et al (2015) and other similar approaches such as Sankar & Seitz (2012) and G. Pintore et al. (2014) have more focused on the technical aspects of capturing the room using smartphone devices.

The limitations discussed above however in the context of end-user creation might be sufficient to provide the environment needed. For instance, if the goal is to provide the end-user a basic environment to exercise a simulation where minor details of extrusions of walls, wall skirtings and colouring of walls are not necessary to immerse the end-user during exercises, then these tools potentially provide a great foundation for end-user creation of virtual 3D simulations. However, methods to enrichen the environment such as windows, doors, and materials on walls for instance should probably also have been researched in this thesis paper but since this study primarily investigated two different methods of capturing the shape of the room, I believe this was the right call, due to the number of tasks the participants already were asked to do with the limited time they were given. Looking at the methods for adding these objects the related work and what MagicPlan already has in its system architecture is quite similar. For instance, both MagicPlan and Santos et al. (2011) allow the user to place these objects on the 2D grid. Furthermore, methods for enriching the environment with objects such as in this case, hospital beds, tools, cabinets, etc. needs to be further researched. The most common approach to this however is providing a catalogue of premade 3D objects the user can place within the room such as (Fischer et al., 1990; Santos et al., 2011; Varlamis et al., 2000; Vosinakis et al., 2007). To expand, Zhong & Liu (2014) for instance designed their tool (iVirtualWorld) to more easily communicate with the end-users using a domain-oriented approach to the user interface. Since iVirtualWorld only provides a generic lab room, it could therefore be interesting to investigate how one could design a domain-oriented approach using the virtual environment created with either of the two approaches investigated in this master thesis.

4.2.1 Tailoring-power

Another important aspect to address is the extend of tailorability of end-user creation of virtual simulations. One of the most important aspect of end-user development is to allow the end-user the tools to adapt and develop systems for their use (Lieberman et al., 2006). With the approaches researched in this paper, an end-user could in fact be able with a short amount of time be able to create new or modify existing environments to different usages. The two interfaces and the finalize stage which both interfaces provide, the levels of tailorability these interfaces provide can be categorized. Starting at A. Mørchs (1997) lowest level of tailorability, “customization”, which is explained in the theoretical background as a way of modifying objects appearances or values. This study showcases that during the finalize stage, the participants were able to modify existing rooms (the ones that they had creating), by altering the parameters with different approaches. For instances some of the participants would drag and adjust the walls according to the desired length of each wall, but person 5 for instance, used the application interface to manually change the parameters. To put this into perspective, if the end-user would have an existing room which they desired to be “customized”, then the study reveals that the end-user could in fact achieve this. Furthermore, A. Mørchs (1997) higher level of tailorability is “integration”, meaning as explained in the theory section is “adding new functionality to an application without specifically access the underlying code, but rather joining predefined components across the application”. Based on the results of this study, person 4 was able to alter an existing room to add additional walls afterwards in the finalize stage, resulting in changing an existing component to more fulfil the shape of the room. Additionally, even though it has not been researched in this thesis, if the end-user would want to “integrate” an existing room to another room, for instance combining room 1 and 2 showcased in this study, the user could in fact drag a room 1 into room 2, combining the two increasing the complexity of the room layout. However, this was not tested during the usability test. Lastly, at the highest level of tailorability named extension presented by A. Mørchs (1997), the user should be able to add new functionalities by improving and adding new code. If we were to consider the two interfaces researched in this paper as an abstract method of programming virtual 3D environments and imagining the end-user development tool that one day might be available to an end-user in terms of end-user creation of virtual simulations, then adding new functionalities such as providing new environments are based on this study a possibility. For instance, initial designs become outdates as changing requirements becomes apparent (Lieberman et al., 2006), and if we consider the new requirements as virtual environments to be used in different situations, and therefore it is required to create a simulation within a new environment not previously created, the end-user could with these interfaces achieve this, with the limitations that are explained previously.

As explained in the theory the gentle slope of complexity by MacLean et al. (1990) suggests that at each step the end-user learns more from the system, the end-user expands the complexity of what they can achieve. In this research however, the participants immediately began at the highest level of tailorability in terms of interfaces to use for creating the rooms, starting at creating the room before being introduced to simple customization exercises, and afterwards tailored the output with simpler customization techniques. Even though, the results indicate that the approaches used in the usability test were user-friendly enough to immediately begin with, it would be interesting to see what the effects would be if the participants were first introduced with simpler versions of the rooms they could interact with and modify, and then create new rooms themselves increasing their knowledge before given the task.

4.3 Societal contributions

As stated in the results chapter, the participants in this study expressed the importance of virtual and non-virtual simulations in their workplace and education for instance, training for different scenarios or drug management. It was also stated by the participant the usefulness of virtual simulations for minimizing cost in terms of location, as participants in the virtual simulations could interact remotely or in a meeting room. A literature review of 3D virtual worlds (3DVW) in healthcare written by (Ghanbarzadeh et al., 2014) support the idea of benefits of 3DVW in healthcare, and argues that it could benefit in a variety of domains. For instance, the authors list: "health decision-makers, universities, educational communities, hospitals, physicians and practitioners, nurses, patients, nursing homes, pharmaceutical institutes, health marketers, disaster managers, psychologists, public health providers, clinical medicine, addiction treatment institutes, etc". More specific, the results of the study argue that 3DVW is beneficial for remote training for education, increasing experience and preparedness of disaster management or even entertainment in nursing homes. The study reveals more benefits in healthcare, but it showcases the importance of virtual simulations in healthcare. Based on this, and on the feedback from the domain experts in this study, I believe enabling end-users to create virtual simulations to their need could potentially be a great societal contribution in aspects such as safety, preparedness, effectiveness, and cost. However, it is important to note that a potential challenge for the virtual simulations created by an end-user could be the validity of the virtual simulation created with an EUD-tool. For instance, if an end-user (a domain-expert) creates a virtual simulation with an EUD-tool, how can we make sure that the simulations and the procedures or tasks within the virtual simulation is correct? This could potentially lead to training or learning the tasks wrong and therefore measures to avoid this should be researched.

4.4 Limitations

Recruiting participants to a physical usability test in the Covid-19 era was challenging because of the sudden national lockdowns that varied throughout the duration of this master thesis. Due to these factors, people asked to participate in the study could potentially have been reluctant to participate. Additionally, due to the lockdowns restricting me and the participants from accessing the location, it was hard to find the time to allocate the time for the usability tests as the lockdowns in Norway would vary. As a result of this, I was only able to complete the usability test with five participants even though I had confirmed seven participants in total to participate. I do recognize that this number of participants might not be necessarily a high number of participants, and ideally the number of the participants should have been higher.

5 Conclusion and future work

In this master thesis, I have investigated two approaches for end-user creation of virtual 3D environments in context of end-user development. To answer the following research question: "Which type of user-interface is most beneficial to support the easy and effective end-user creation of virtual 3D environments for virtual task-training in healthcare?", I identified in the related work, two methods of end-user creation of virtual 3D environments I decided to investigate in terms of usability. To answer the research question, I used a breakdown structure as an analytical framework for investigating how each approach performed in terms of usability, and a score system to score each approach on accuracy. Based on the results and discussion, I suggest the camera method as a fitting approach for end-user creation in terms of usability and accuracy in context of capturing an existing room. If it is the case that the end-user would want to create based on imagination, as stated in the results the camera method is not suitable. However, it is important to note that both methods were quite similar in terms of accuracy, but I base my recommendation on the fact that most breakdowns and the participants feedback skewed favourable towards the camera method. But it would also be a requirement to provide the participant with the finalize stage as well to provide the end-user to alter their capture of the room.

In context of end-user development, I identified in this master thesis what could be a foundation for end-user creation of virtual simulations. Meaning, the tasks given to the participants were to 3D model a given room, and only the shape of the room. The task did not include decorating the room or creating any simulations within the virtual environment. I therefore recommend taking the next step at end-user creation of virtual simulations to investigate how end-users can decorate rooms in terms of complexity and usability, and how end-users can create virtual simulations within the created virtual environment.

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Appendix A: Results

In this appendix, I present the results in a more in-depth manner than the thesis paper and I use this appendix to reference in the main paper. Like the results chapter, I present the results from each participant separated by the other at first, showcasing their completion of the task given, with an in-depth view of their progression. Following I present a comparison of the results of all the participants. This includes the accuracy of each person's output compared to the other, and their statistics regarding completion time. When referring to breakdowns, I sometimes use the abbreviation "B1" for instance to refer to "breakdown 1". I may also use the abbreviation "P1" for instance to refer to "person 1" and "R1" for "room 1". Furthermore, in this chapter I present figures such as Figure 31, in this figure there are numbers aligned on a straight line. These numbers are to address the minute mark during the usability test. Following, the same figure is made to provide a general overview of the events that occurred during each method and room. While illustrations such as Figure 32 are presented to provide a general overview of the sequence of events that occurred during each breakdown.

7 Contents

7.1 Table of contents

7.2 Figure list

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8 The ground truth

The ground truth for the first room used to compare the output for each participant can be seen in Figure 28. Looking at Figure 28, walls categorised in alphabetical order is presented to be able to specify what walls that are referenced or compared to during the results chapter. This has also been explained in greater detail in the methods chapter. However, I also present the following measurements of each wall for room 1 in meters seen in Table 22.

Wall	A	B	C	D	E	F	G	H
Length in Meters	2.57 m	3.17 m	0.88 m	0.28 m	1.27 m	0.35 m	0.22 m	2.64 m

Table 22 Room 1 ground truth measurements

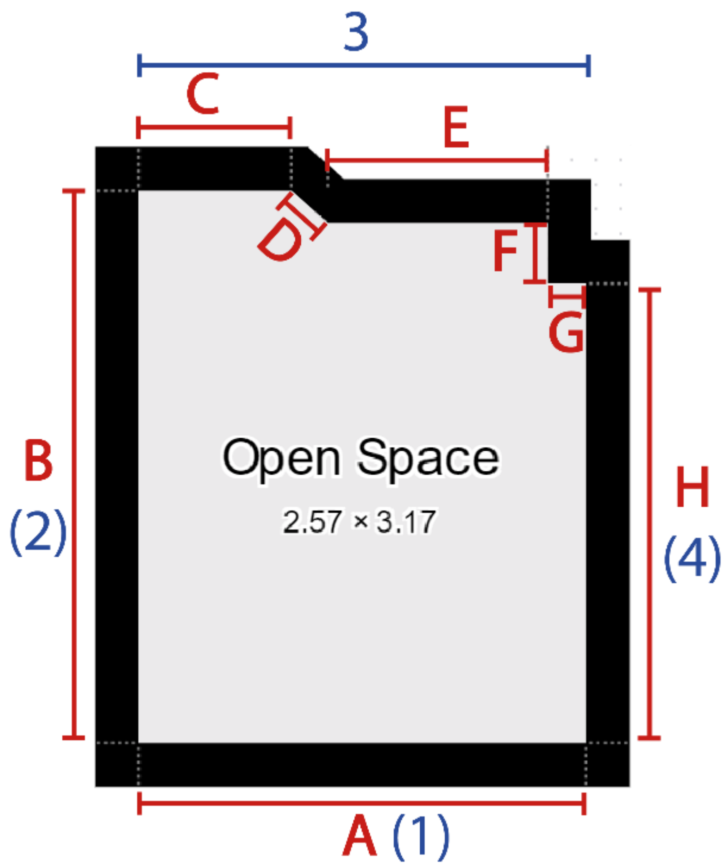

Figure 28 Ground truth room 1

The second room seen in Figure 29, which is used to compare contains 19 walls in the ground truth. It however is the case that some participants have decided to skip or not include certain walls such as B, C, D E. For those who have not included those, have included the length to wall A. Other spots such as wall G, H and I is also skipped, and the walls will be merged to F and J, same goes for wall L, at this wall, K and M will be merged as well. In Table 23 the measurement of each wall is presented with reference to Figure 29.

Wall	Length in Meters
A	4.90 m
B	0.26 m
C	0.53 m
D	0.26 m
E	0.20 m
F	6.53 m
G	0.18 m
H	0.62 m
I	0.18 m
J	3.26 m
K	6.01 m
L	0.26 m
M	1.65 m
N	2.87 m
O	2.12 m
P	2.68 m
Q	3.32 m
R	2.96 m
S	3.32 m
T	2.66 m

Table 23 Room 2 ground truth measurements

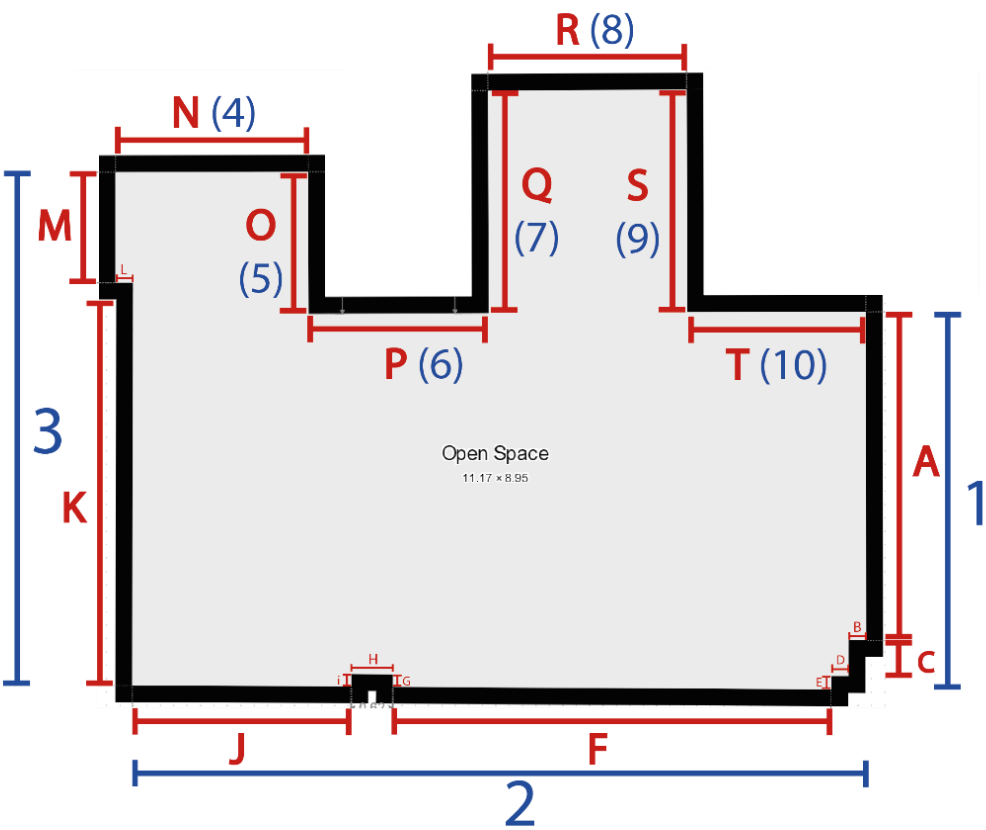

Figure 29 Ground truth room 2

9 Group 1

As explained in the method chapter, I have divided the participants into two groups. The first group, person 1, 2 and 3, are starting with using the drawing method first, with the camera method following.

9.1 Person 1

9.1.1 Basic info

Person 1 was a female at an age above and close to 60 years old. The informant placed herself between 3 and 4 on the Likert scale describing the skills of using a smart phone. Furthermore, the informant informed that she had no prior experience with similar tools provided in the usability test. She told however that she had used methods such as rulers to measure lengths of a room before.

9.1.2 Room 1

Effectiveness

Person 1 was able to complete the first room 11 minutes and 55 seconds faster with the camera method compared to the drawing method (see Table 24). Additionally, the participant completed the objective with one less breakdown. Even though the number of breakdowns is similar, person 1, used 12 minutes and 33s longer total on the breakdowns for the drawing method compared to the camera method. The camera method also scored 7 out of 8 total points, meanwhile the drawing method only scored 4 out of 8 total points (see Table 25).

Room 1	Drawing	Camera
Time spent per method	15m 43s	03m 48s
Time spent difference	11m 55s	
Number of breakdowns	6	5
Total time spent on breakdowns	14m 7s	1m 34s

Table 24 Person 1 room 1 completion overview

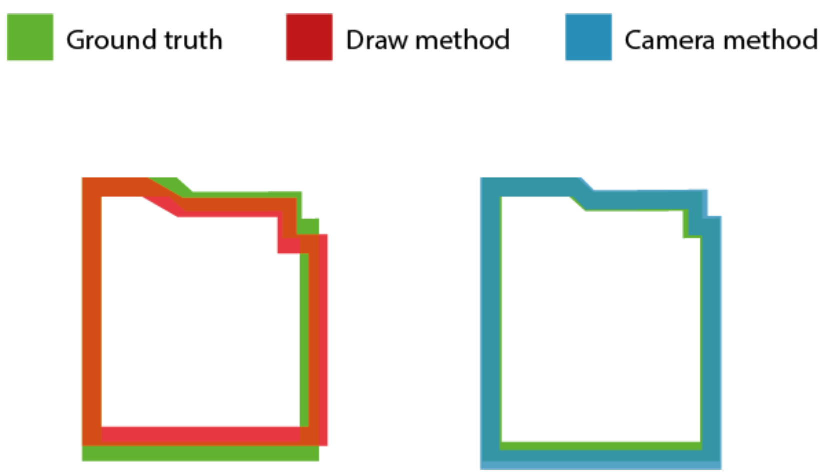

Figure 30 Person 1 Room 1 Output

Person 1 - Room 1

Wall	Ground truth	Drawing	Score	Camera	Score
Wall A	2,57m	2,69m	1	2,62m	1
Wall B	3,17m	2,98m	1	3,27m	1
Wall C	0,88m	0,53m	0	0,95m	1

Wall D	0,28m	0,53m	0	0,24m	1
Wall E	1,27m	1,29m	1	1,33m	1
Wall F	0,35m	0,47m	0	0,34m	1
Wall G	0,22m	0,40m	0	0,17m	0
Wall H	2,64m	2,24m	1	2,77m	1
Max score			8		8
Sum score			4		7

Table 25 Person 1 Room 1 Score

Learnability timeline

Draw method

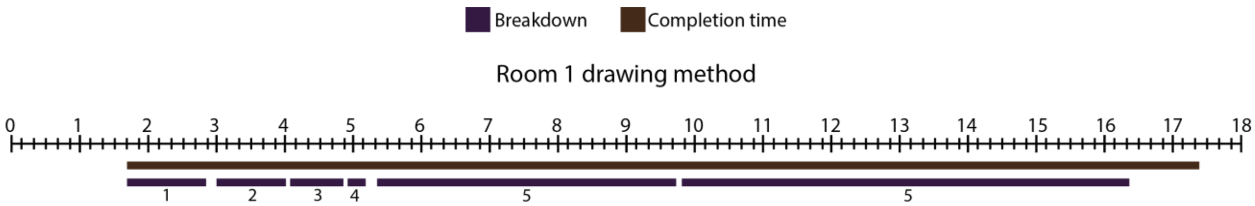

Figure 31 P1 R1 Breakdowns drawing

When starting the drawing method for room 1, the participant was given a brief explanation for how stage 1 of the drawing method worked. The person was told that 1 meter in real life was the same as 1 square on the grid, and to draw a wall, the person had to tap for each corner point. This was not demonstrated to the test subject, only told verbally. This was not understood by the participant, which lead to the first breakdown.

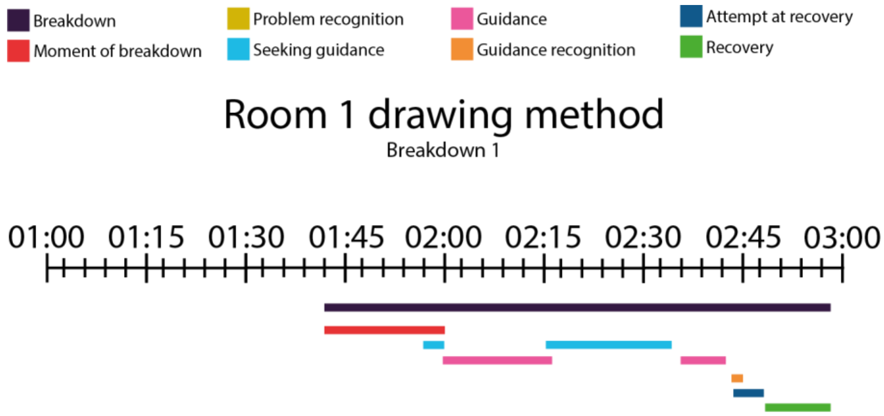

Figure 32 P1 B1 R1 drawing

Breakdown 1 - placing corner points: The participant showed confusion when trying to draw each wall. During this breakdown, the participant had issues understanding that to draw each wall, multiple corner points had to be made. The participant however understood it as she had to drag the first corner point to the second point of interest, rather than placing one corner point followed with another to create a wall. At this point the participant asked me for guidance to understand how this worked. I understood it at that point that the participant needed help with understanding how to adjust the corner to be made, so I gave brief explanation to how one may adjust the corner point. Once again, the participant asked for guidance, but this time, it was clear that she had misunderstood the concept, and I gave a more in-depth explanation to the participant, that to create a wall, she had to first tap at the screen for the first corner to be created, then followed with another tap at the next corner location. The participant recognized this guidance and attempted to create a wall based on this information and succeeded with the creation of the first two walls of the room starting at the left bottom corner of the room. At this point, the participant seems to understand the concept of creating a wall.

In between breakdown one and two, the participant continued with attempting to create the angled wall D.

Figure 33 P1 B2 R1 drawing

Breakdown 2 – placing corner points and adjusting corners: The participant initially attempted to create the shape of the room by placing multiple corner points following the shape with the idea that she could adjust the corner point to follow the angled shape of the wall after a few corner points were set. However, the participant was not able to adjust the corner, even though she was explained how this was achieved in breakdown 1. At this point, the participant did not seek guidance, but attempted to solve the problem by herself. Just a few seconds in, she decided to continue with the rest of the walls before she would adjust the angled wall. During this continuation, she had issues with creating new corner points which made the participant visibly frustrated. When the participant attempted to place new corner points, she was not able to create the shape she desired. To fix this, she decided to undo her actions to the start of the breakdown. At this point she was clear that the angled wall had to be adjusted at some point later and was more assertive with her taps on the screen. Even though she recovered from her breakdown and were able to move on, she was not able at this point adjust the desired corner point.

Figure 34 P1 B3 R1 drawing

Breakdown 3 – placing corner points: Once the participant continued with creating the shape of the room, another breakdown occurred. This time she had issues with placing new corner points once again.

The participant was quite clear that she desired to place a corner point downwards, but during this, she had placed a corner point at an undesired location resulting in a wall that was not intended to be created. She recognized this, and made one undo click, and attempted to create the wall once again, and the same outcome occurred. At this point she realized she did not remove the unwanted corner point, and pressed the undo button twice, and moved on to create the desired wall resulting in a successful recovery.

At this point, the participant expressed that she was rather satisfied with the result so far except for the angled wall she was not able to fix.

Figure 35 P1 B4 R1 drawing

Breakdown 4 - completing drawing: At this point, when she expressed that she was satisfied, I proceeded to explain to her that all corner points must be attached to create the room, suggesting that she may have thought that she would not draw a wall where a door was placed. This was understood by the participant and attached the corner points by clicking on the first corner point, entering the participant to the finalize stage.

To this point, the current measurements of the room had not been a concern or though from the participant based on my observations. But once the participant had completed defining the corners of the room, and entered the finalized stage, I reminded the participant that she could now examine the lengths of the walls. This led to her realizing the measurements were wrong, leading us to breakdown 5.

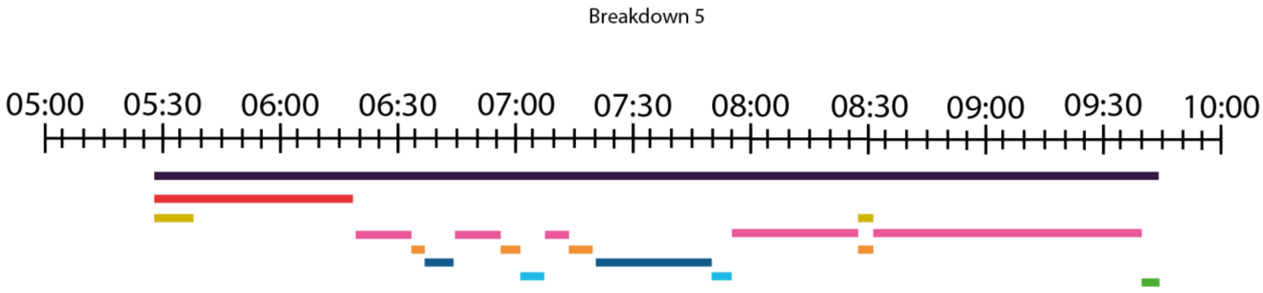

Figure 36 P1 B5 R1 drawing

Breakdown 5 – Adjusting corners: The current measurements at this point were drastically larger than the ground truth and this was as stated above. The participant expressed that at the measurements must be wrong and pointed at the angled wall corner of the room. She decided to adjust the angled wall that previously was not fixed. I briefly explained at this point, that she could now adjust the walls based on the corner points and walls, in which she attempted to do. During this, the participant had issues with being efficient when using the interface. She attempted to adjust the corner points from a very zoomed out perspective resulting in a less detailed perspective, making it hard for the participant to adjust the corners efficiently. At this point, I without her seeking guidance, I reminded her that she could zoom to gain a better detailed overview. She proceeded to zoom in, but in a hesitant manner as if she is scared to alter the corner points. At this point, she attempted to adjust the angled wall, but clearly struggled with understanding how she could achieve this. I give her specific instructions that she can zoom in a bit more and select the rounded circle of the corner point to specifically access it, and to then adjust is accordingly. She proceeded to zoom in more and tried to click on the corner point without success, and still needed guidance for how this could be achieved. I once again, reminded her to tap the corner point, in which she responded to successfully target the desired corner point, and moved on to attempt at adjusting the desired corner points. During this, she struggled with selecting and adjusting the corner points, and still struggled with understanding the difference between adjusting a wall and adjusting a corner point. She was clearly confused at this point and needed guidance once again. And I give her precise instructions for how she could adjust a corner point. During this guidance she attempted to press the corner point but struggled. Once she targeted the corner point, she realized that once the arrow appeared, she had selected the corner point, and she understood at this point that to adjust the wall the way she wants, she had to achieve this.

This moment of realization was confirmed to be an “a-ha” moment for the participant during the interview. Throughout the breakdown at this point, she struggled with being efficient when using the interface, but she started to understand how she could manipulate the corner points to achieve her desired goals. She recovered from the breakdown with her fixing the angled wall, and more knowledge. During the interview, she also expressed that this moment was very frustrating.

I once again reminded the participant about the measurements the interface displays at the finalize stage, because she did not alter the measurements when I reminded her earlier.

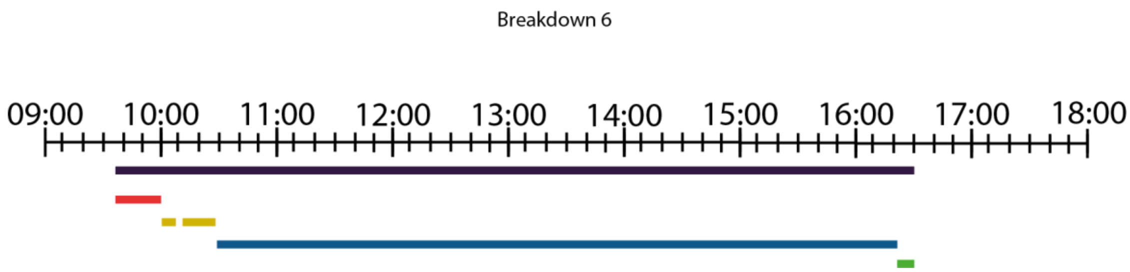

Figure 37 P1 B6 R1 drawing

Breakdown 6 – capturing measurements: When I reminded her of the measurements, I gave her an example of the drawing, where one of the walls were 20 meters long, while the ground truth is 3 meters. She instantly understood this to be a wrong measurement and proceeded to starts doing measurements with walking across the room to capture the real-world measurement of the wall. Before she began, she recognized that it was probably more efficient to adjust the wall from beneath and not from the top, as that area contained a lot of corner points. From this point on, she proceeded to adjust all the corner points to capture the rooms real dimensions. She understood how to use the interface at this point, but she clearly lacked the skills to use it efficiently, making the adjustments take quite a long time to achieve. She did in the end achieve the goal of capturing the room with measurements she trusted to be as close as she could get.

At this point, she decided that the was pleased with the results, and expressed that she literally forgot the measurements, and then specifically that 1 meter was the same as 1 box on the grid. This was later confirmed in the interview to be true, as she expressed that “when I completed the first room, I was only thinking about the shape of the room, and not the measurements". She also expressed in the interview that she would like some sort of instruction or reminder that each square was equal 1 meter.

Camera method

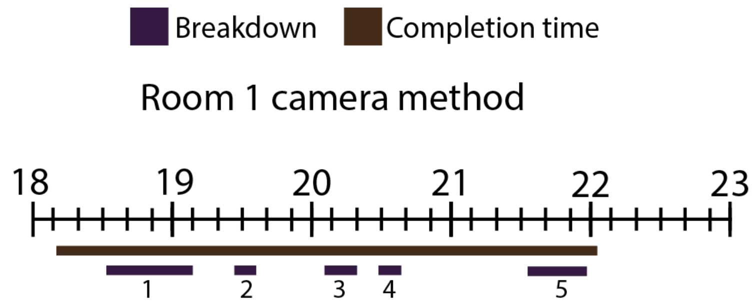

Figure 38 P1 R1 Breakdowns camera

When the participant was given the task to capture the room with the camera method, I gave the participant instructions to follow the instructions of the application. Meaning, she was to follow the instructions of the application to initialize the camera method.

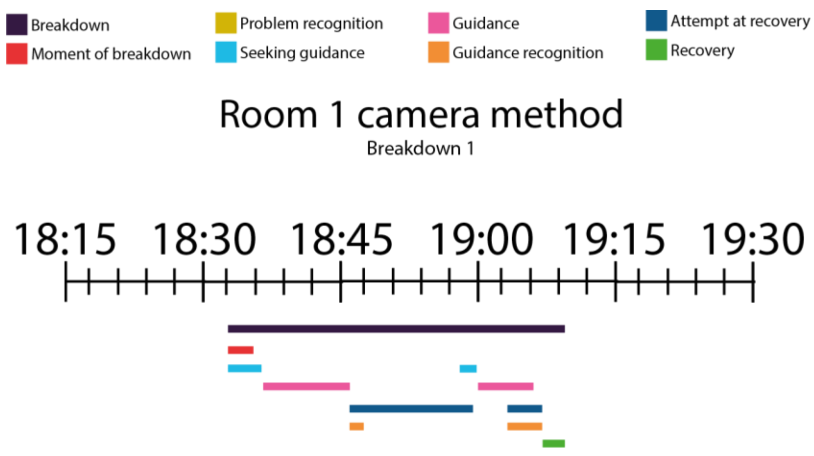

Figure 39 P1 B1 R1 camera

Breakdown 1 – initializing camera method: The participant started by being confused by the instructions of the application, asking me if it mattered if she had to scan the floor or the wall. During the interview, this was also clearly expressed as a confusing moment. I proceeded to instruct her to move the camera around the room while telling her that the application was trying to find reference points, and to follow the instructions of the application which at that point instructed the same instructions that I gave. She proceeded to scan the room without the application initializing. It seemed that she did not understand why she was doing what she was doing and proceeded to ask if she should follow the instructions of the application. I gave her a tip that she could maybe try to initialize the camera method outside the current room she is inside. She responded to this, walking outside the room and the application then proceeded to initialize. At this point the application will tell that it is ready to go, and she recognized this, and express that she was ready.

Once she was ready to capture the room, I explained to her that she now had to place the green pole at each corner of the room to capture, without specifying that she had to aim it at the ground. Which leads us to the second breakdown.

Breakdown 2

Figure 40 P1 B2 R1 camera

Breakdown 2 – placing corner points: She stood still by the corner aiming at the corner, which she was told, but she was not aiming at the ground at this point, which the camera method required. I instructed her quick to aim at the ground, and she proceeded to do this. Once the application registered the corner point, she instantly recognized that the application captured the corner.

At this point, she instantly recognizes that she had to do this activity to each corner without me telling her so, moving on to the next corners without hesitation. Even expressed that this was fun. It was also expressed during the interview, that she found the interface quite self-explanatory at that point.

Figure 41 P1 B3 R1 camera

Breakdown 3 - placing corner points: However, when the application did not recognize the corner automatically, she became confused. However, she recognized this problem quickly, and asked me if it was possible to tap herself if the corner point was not automatically placed, in which I said yes. This was recognized and was recovered successfully by simply taping the desired spot herself.

Figure 42 P1 B4 R1 camera

Breakdown 4 – placing and confirming corners: The participant quickly moved from corner to corner, but once a shelf was in the way she expressed some concerns that it might be in the way but attempted anyway. The application recognized the corner behind the shelf by itself when aiming towards the corner in front of the shelf. The participant trusted that this was correct and moved on.

The participant continued with connecting all corner points when she was done and proceeded to setting the ceiling height stage. At this point I gave her brief instructions to aim at the ceiling and tap the screen once she was satisfied. She recognized the tip and proceeded to set the ceiling height. The participant was rather satisfied with the result, but the automatically placed corner from breakdown 4 appeared to be slightly misaligned resulting in one of the walls being rather skewed.

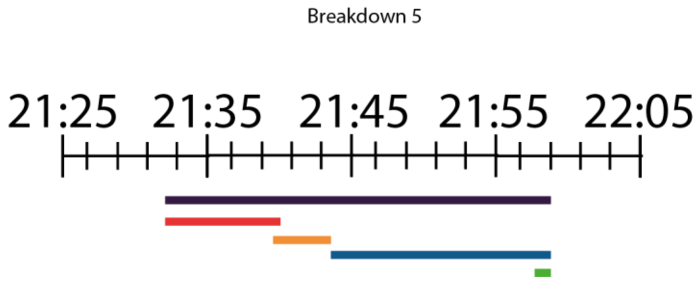

Figure 43 P1 B5 R1 camera

Breakdown 5 - finalizing: Because of the misaligned corner point, I told the participant that she could now adjust the corner points the same way she did in the finalize stage on the drawing method. She recognized this tip, and simply realigned the corner point making a 90-degree angle, which was correct in terms of the shape of the room.

The participant was satisfied at that point and decided to not alter any measurements at this point.

9.1.3 Room 2

Effectiveness

It took the participant 2 minutes and 14 seconds longer to complete the capturing of room 2 when using the drawing method compared to the camera method, with one more breakdown in total (see Table 26). However, it took the participant a total of 51 seconds less on both the breakdowns combined compared to the one breakdown using the camera method. Additionally, person 1 scored a total of 8 points with both methods out of a total of 20 points (see Table 27). When comparing the points, the participant scored the same points on all the walls, with the participant skipping the same details such as the smaller walls in the bottom right corner with both methods.

Room 2	Drawing	Camera
Time spent per method	7m 14s	5m
Time spent difference	2m 14s	
Number of breakdowns	2	1
Total time spent on breakdowns	2m 27s	3m 18s

Table 26 Person 1 Room 2 completion overview

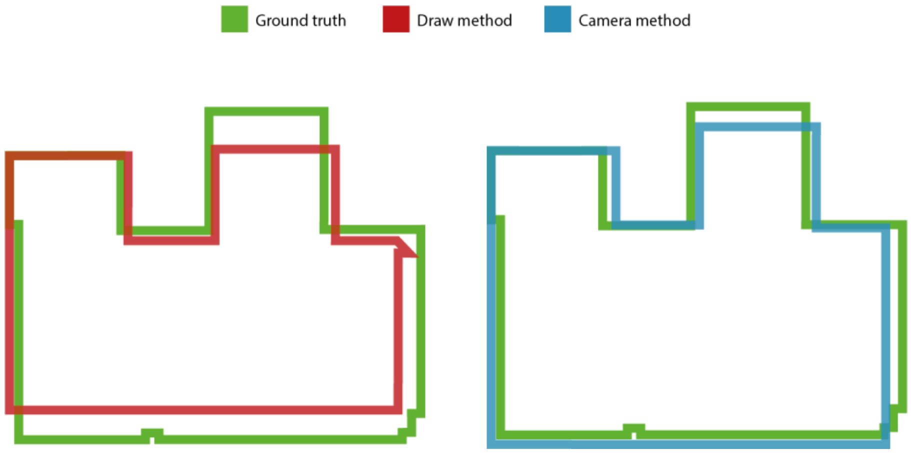

Figure 44 Person 1 Room 2 Output

Person 1 - Room 2

Wall (combined)	Wall	Ground truth (meters)	Ground truth (combined)	Drawing	Score	Camera	Score
Wall 1 (A+C+E)	Wall A	4,9m	5,63m	4,48m	1	5,78m	1
	Wall B	0,26m					
	Wall C	0,53m					
	Wall D	0,26m					
	Wall E	0,2m					
Wall 2 (B+E+F+H+J)	Wall F	6,53m	10,93m	10,58m	1	10,74m	1
	Wall G	0,18m					
	Wall H	0,62m					
	Wall I	0,18m					
	Wall J	3,26m					
Wall 3 (K+M)	Wall K	6,01m	7,66m	6,84m	1	7,93m	1
	Wall L	0,26m					
	Wall M	1,65m					
Wall 4	Wall N	2,87m		3,06m	1	3,22m	1
Wall 5	Wall O	2,12m		2,37m	1	2,07m	1
Wall 6	Wall P	2,68m		2,67m	1	2,58m	1
Wall 7	Wall Q	3,32m		2,25m	0	2,73m	0
Wall 8	Wall R	2,96m		3,1m	1	3m	1
Wall 9	Wall S	3,32m		2,55m	1	2,81m	1
Wall 10	Wall T	2,66m		1,78m	0	1,94m	0

Max Score	20	20
Sum score	8	8

Table 27 Person 1 Room 2 score

Learnability timeline

Draw method

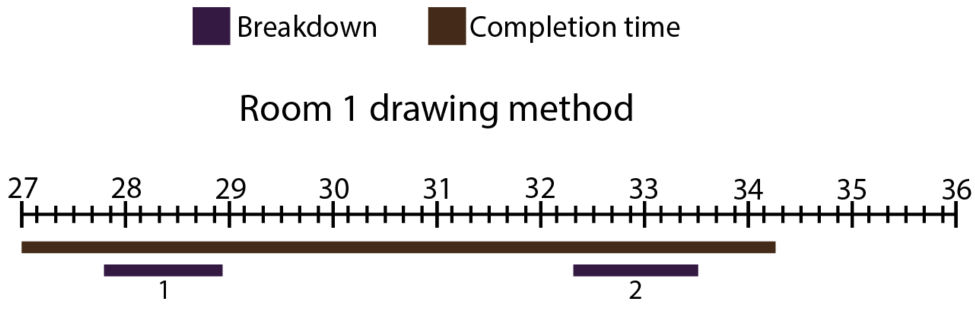

Figure 45 P1 R2 Breakdowns drawing

When starting using the draw method on room 2, the participant was from the beginning concerned with the measuring accurate, starting with measuring the length of the first wall using walking technique from breakdown 6 in the room 1.

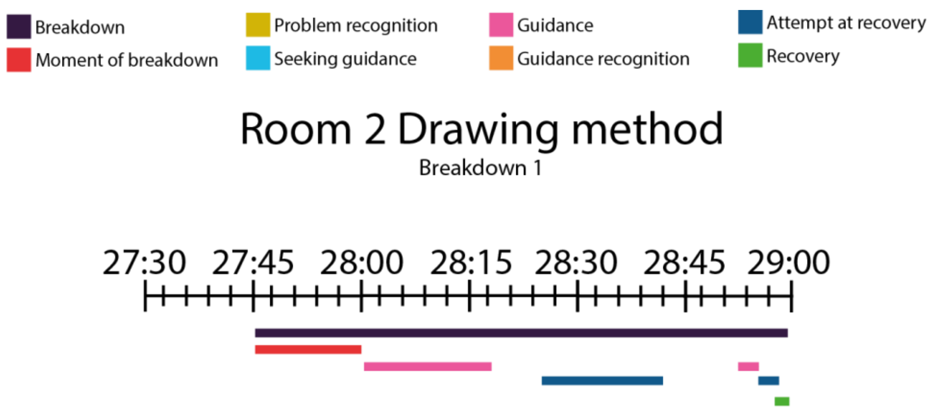

Figure 46 P1 B1 R2 drawing

Breakdown 1 – placing corners: However, when the participant wanted to put down the first corner points, she had issues with placing them in detail. In addition, the location of the grid she had chosen was close to another previously made room she had created. I therefore guided her to choose another location of the grid and zoom into detail once a location was chosen. She agreed to this, and quickly started at another location placing the first two corner points.

From this point on, the participant did not experience any breakdowns for a while when drawing the room. She was generally efficient at placing the corner points, while using her walking techniques to measure the lengths of each wall in the room. Her usage of the zooming was not often used, as she generally placed each corner point from a far keeping an overview. Even though she was generally quick at placing the corner points, she skipped a few details, which can be seen in Figure 44.

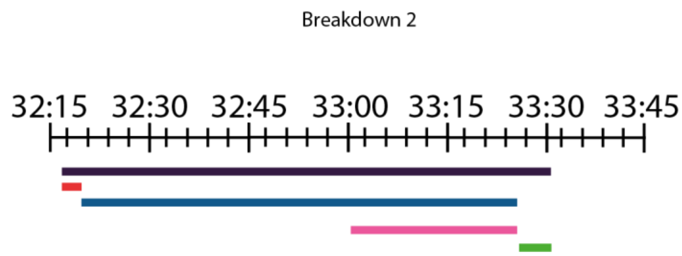

Figure 47 P1 B2 R2 drawing

Breakdown 2 – completing drawing: When attempting to finish the shape of the room, the informant had issues with attaching the last corner point with the first corner point. During this she attempted multiple times to align the corner point on top of the first corner point not realizing that she had to tap the corner point to be attached. I began to help the participant to connect the corner points, but involuntary created a few extra corners in the process as seen at the right side of the room on Figure 44. This was recognized, and we agree that some error has occurred, and she decided to not fix it.

Once she and completed and entered the finalize stage, the participant decided that she trusted her measurements. She also expressed after the drawing was complete that the details, she skipped between breakdown 1 and 2 was skipped intentionally as she felt it was not necessary when capturing the room.

Camera method

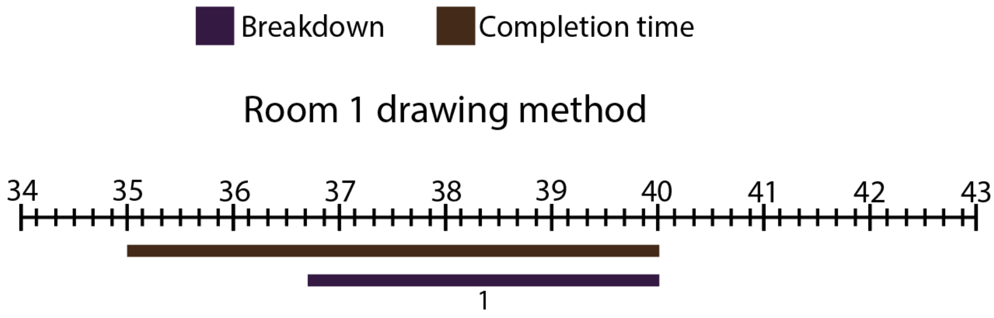

Figure 48 P1 R2 Breakdowns camera

The participant started quickly when using the camera method. This time the participant had no issues with initializing the camera method and began quickly at placing down the first two corner points, as if she is guided by the interface. When the participant reached a corner where were cabinets in front of the corner, the participant decides to place the corner point in from of the cabinet and addressed the inaccuracy verbally. At this point, it was unclear whether she would address this inaccuracy later, but she moved on capturing the room. Further on the participant was very efficient at placing each corner point by aiming very close to each corner, looking like she wanted to be very accurate. When obstacles such as furniture's appear, she decided to move them if she could move them by herself to be able to place the corner point. Same as with the drawing method, the participant decided to skip the details at the bottom of the room, which can also be seen in Figure 44.

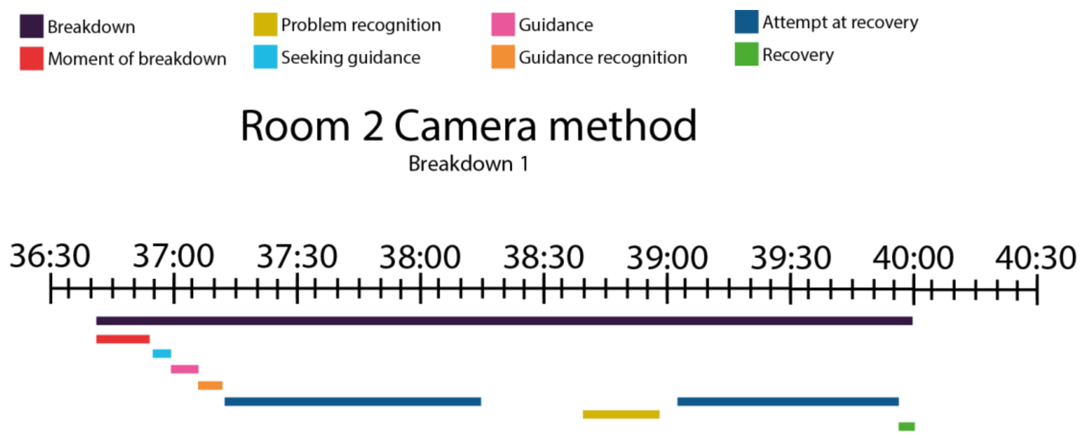

Figure 49 P1 B1 R2 camera

Breakdown 1 – placing and confirming corners: When the participant believed she was done, she recognized that she had to connect all the corner points to form the shape of the room. On her way to connecting the last corner points she tapped the screen involuntary, creating multiple corner points on the way. Once she had placed the last corner point, she thought she had connected the corner points, but instead only created another corner point close to the once she was supposed to connect it with. As a result of this point, she was confused and were seeking guidance. This confusion was also expressed during the interview as a moment of frustration and confusion. I addressed the issue and informed her that she did not connect the corner points. She proceeded to walk back to the corner point and connected them. She then moved on to set the ceiling height without any many issues. Once she entered the finalize stage, she now recognized the extra corner points created towards the end. Before this point, she was unaware of this, and said "I must have clicked on something". She quickly realigned the extra corner points, creating one straight wall easily.

Once she fixed the breakdown 1 issue, she decided that she was satisfied with the result. She did not mention or decide to adjust the inaccuracy previously addressed before breakdown 1. It was later addressed during the interview that she probably could have fixed it in the finalize stage, but up until that point in the interview, she did not think of it.

9.1.4 General thoughts from the participant

The participant expressed during the interview that she found the camera method more pleasing to use, as this interface gave more direct instructions for achieving the capture. Instructions and feedback such as colours, sounds and general visual feedback helped her understanding the process of capture. For instance, she expressed “when I see the room through the camera and got the feedback when I pointed the camera towards the corners it was firstly, very logical for me, secondly, it gave a feeling of mastering and thirdly, I trusted it”.

9.2 Person 2

9.2.1 Basic info

Person 2 was also a female at the age close and above 60 years old. She placed herself as a 4 on the Likert scale, as she claimed to use the smart phone a lot, but not an app like this. Similarly, to person 1, person 2 had not used any applications to draw on or measure and capture a real-life room before, and only used a physical ruler to measure lengths.

9.2.2 Room 1

Effectiveness

The participant used two attempts at creating room 1 with the drawing method, with the first attempt taking 5 minutes and 12 seconds, while the second attempt took 3 minutes and 32 seconds. Combined, both attempts took 8 minutes and 39 seconds. Compared to the camera method, both attempts with the drawing method combined took the participant 5 minutes and 7 seconds longer to complete than the camera method (see Table 28). During both attempts, the participant experienced two breakdowns while in the camera method; the participant also experienced two breakdowns. However, the participant used a total of 6 minutes and 27 seconds on the breakdowns for the drawing method, compared to the 1 minute and 20 seconds on the camera method, resulting in a 5 minute and 7 seconds difference in time used on breakdowns. Additionally, the participant only scored 2 out of a total of 8 points with the drawing method, compared to the camera method with 8 out of a total of 8 points (see Table 29).

Room 1	Drawing	Camera
Time spent per method	5m 12s	3m 32s
Second attempt	3m 27s	
Time spent difference	5m 7s	
Number of breakdowns	2	2
Total time spent on breakdowns	6m 27s	1m 20s

Table 28 Person 2 Room 2 completion overview

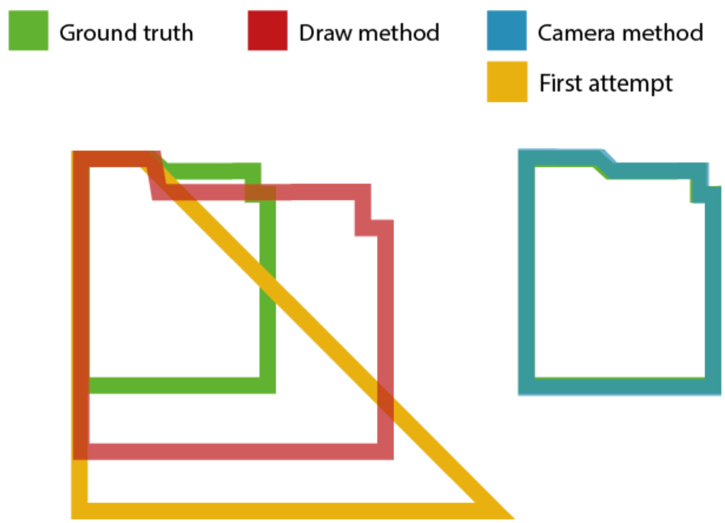

Figure 50 Person 2 Room 1 Output

Person 2 – Room 1

Wall	Ground truth (meters)	Drawing	Score	Camera	Score
Wall A	2,57m	4,36m	0	2,57m	1
Wall B	3,17m	4,17m	0	3,23m	1
Wall C	0,88m	0,87m	1	0,94m	1
Wall D	0,28m	0,51m	0	0,28m	1
Wall E	1,27m	3,06m	0	1,25m	1
Wall F	0,35m	0,54m	0	0,37m	1
Wall G	0,22m	0,35m	0	0,19m	1
Wall H	2,64m	3,12m	1	2,65m	1
Max score			8		8

Sum score	2	8

Table 29 Person 2 Room 1 score

Learnability timeline

Draw method

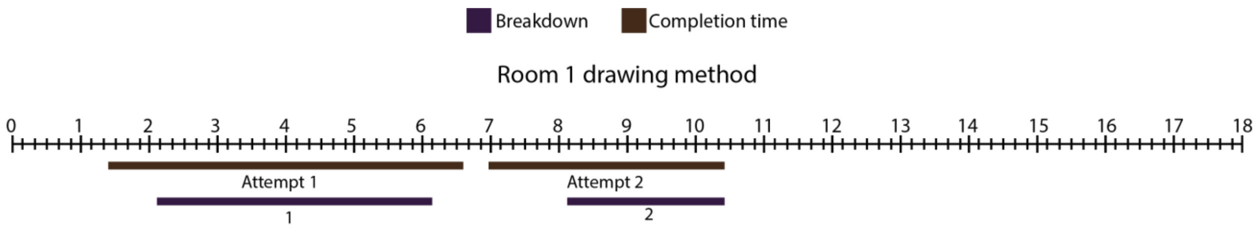

Figure 51 P2 R1 Breakdowns drawing

When the participant was given the task at capturing room 1 with the drawing method, I explained that the grid on the interface had squares in which each of the squares was 1 meter in real life. I then went on to explain that if she wanted a larger overview, she could zoom out and zoom in to get a more in-depth detailed view of the grid. Furthermore, she was explained that she was to create the shape and measurements of the room by simply adding corner points on the grid, and it was explained that she had to place 1 corner point to another 1 to create a wall. This seemed to be understood by the participant until she got the angled wall.

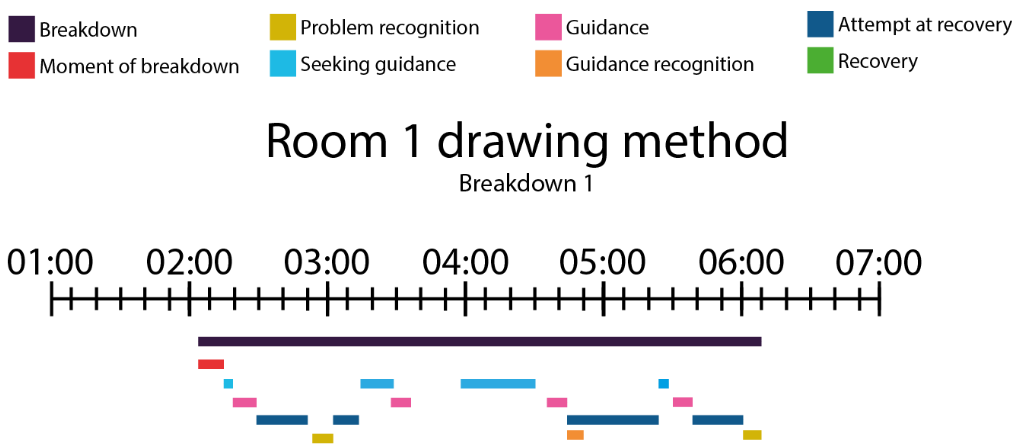

Figure 52 P2 B1 R1 drawing

Breakdown 1 – placing corners and adjusting corners: Once the participant reached the angled wall in the room, more details had to be put in place. At this point, the participant attempted to place down corner points without zooming anything, and therefore attempting to place corner points from a perspective that is hard to see details. This resulted in the participant placing corner points at locations the participant did not desire. At this point, the participant was confused and asked if she could remove some corner points, in which I responded with yes, by simply pressing the undo button. She proceeded to press the undo button and continued to attempt with the creating the angled wall. It was clear at this point, that she struggled with utilizing the interface efficiently, using little to no zoom and was very careful at placing each corner point, and all corner points had to be undone by the undo button. At this point in the breakdown, she expressed that she wished to create the angled wall, but that she does not understand how. Still attempting at placing the corner wall without zooming, she asked vaguely how she could fix the wall to create the angled wall. I at this point, I assumed that she wanted to know how she could adjust a corner point, and therefore explained that if she desired to adjust the corner point, she could simply press the corner point and move it across the screen. She attempted this for a while, but at this point, she was very confused as to what is supposed to be done to create the angled wall. She expressed verbally that she failed to understand and were seeking specific guidance. This time, she asked specifically, how she could place a new point below the original point, to create the angled wall. This time I give her the tip that she should probably zoom in to get a more detailed view, to help her be more accurate with pressing the corner points. The informant proceeded to do so and begin placing corner points. During this she places multiple corner points involuntary and was frustrated and confused during this. She asked for help once again, which I responded with instructing her to press the undo button until the undesired corner points disappear. She attempted to do so, but the undo button only stores a certain amount of undo actions, meaning that she had done so many undesired actions, that she could not undo her work. I asked her if she wanted to restart the task in which she agreed.

Attempt 2

Once it was agreed upon to restart the objective, I reminded her of the way the interface worked, by explaining specifically that each corner point in the application, is the same as each corner point in real-life. This time, she was faster at placing the initial corner points, beginning from the top of the room. By the looks of it, it did not seem like she focused on the measurements, but instead capturing the shape of the room. This seemed to be the case, as she completed the initial drawing quite quickly, by placing the corner points very vaguely and fast.

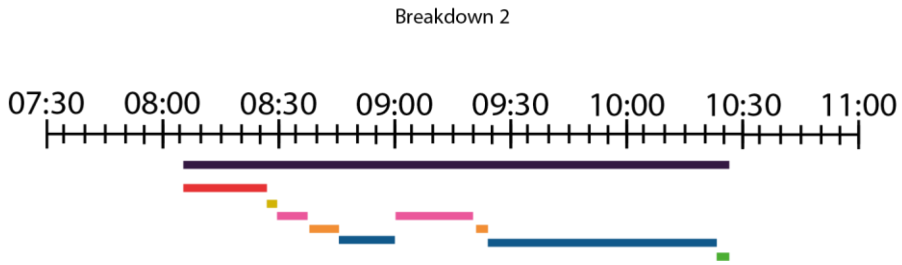

Figure 53 P2 B2 R1 drawing

Breakdown 2 – capturing scale and adjusting corners: Once she completed the drawing and entered the finalize stage, I presented to her the measurements of the room she had created. She realized at that point that the measurements were off. I briefly explained to her that, at that point she could adjust the corner points and the walls by simply pressing the desired corner point or wall, and then drag to the wanted location. She attempted to press a corner point, but pressed a wall instead, and proceeded to move the wall upwards. She did not seem to focus on the measurements at that point, but rather on fixing the angled wall. She attempted this by trying to press the corner point without success, and I gave her the instructions to simply zoom in and press more accurately. She succeeded at adjusting it slightly, and it was somewhat recognized by the participant how it is achieved. She was however, at this point satisfied with the adjustments she made.

In hindsight, it did not seem to be the case that she did any estimates or used any methods to measure the lengths of the room, but rather chose to adjust the measurements based on her own intuition. During the interview she told me that she had to have had a physical measurement tool to make sure she would measure accurately, and at this point was instead estimating. When asked if she knew the measurements, would it be easier, in which she responded with yes.

Camera method

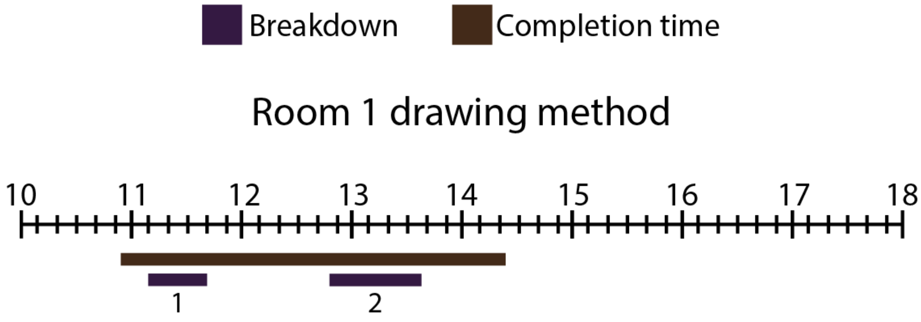

Figure 54 P2 R1 Breakdowns camera

Before the participant began with the camera method, I briefly explained to her that to start this method, she had to aim the camera around the room to initialize it, and even gave her the tip that if nothing happens, she should try to go outside the room. She began with following the instructions made by me, but nothing the application will not initialize, leading us to the first breakdown during the camera method.

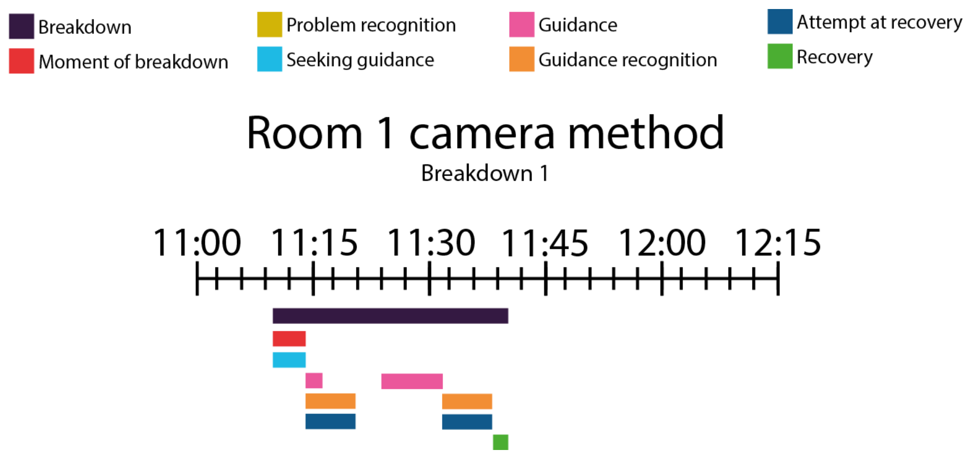

Figure 55 P2 B1 R1 camera

Breakdown 1 – initializing camera method: Once she attempted to initialize the camera method, she specifically asked if she had to move the camera around, in which I responded with a simple yes. She proceeded to move the camera very slowly around the room looking at each corner point, as if she believed that this is the time for creating the room and not initializing it. I proceeded to give her a specific explanation that at this stage the camera only attempts to initialize and if she struggled with initializing it, she could try go outside the current room. She followed my instructions, and the application initialized. She did not recognize this, so I told her that it was now ready. At that point, it seemed like she did not understand what was going on.

Once the application was ready, I proceeded to explain to her that to create the room, she had to aim the green pole towards each corner and the ground. This was acknowledged by the participant as she successfully places the first corner point and walked directly to the next corner without hesitation, but at a slow pace. Once the application automatically suggested the corner, she walked even more towards the corner point to make sure she stands correctly.

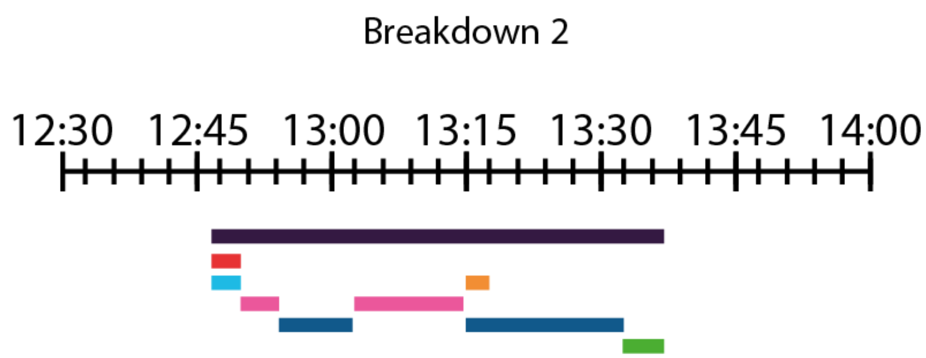

Figure 56 P2 B2 R1 camera

Breakdown 2 – placing and confirming corners: Once she reached a corner where the camera did not recognize it automatically, she began to question why it did not work and were seeking for help without trying to tap the screen by herself. I simply explained that if the program did not recognize it automatically, she could just tap the screen where she felt the corner placement was correct. She proceeded to tap, and a corner was placed, but at this point she was confused whether it was placed or not. I pointed out that the corner point was been placed, and if she wanted, she could press the undo button and place the corner point at another location. She proceeded to press the undo button in confusion, but once she realized she could now place the point on her own, she proceeded to do so without any problems.

Throughout the capturing of the room, she was efficient at placing the corner points, and specifically crouched down to make sure she got the corner point between the empty shelves that is in the way of the corner point. She then proceeded to attach all corner points without hesitation, and when the ceiling height stage appeared, I simply instructed her to point the camera towards the roof and tap the screen when she was satisfied with the height. She followed the instructions by me, but she seems slightly confused, so I point out that she had now completed the objective.

Once she had completed the objective, she decided that she was satisfied with the result, but upon closer inspection she points out that the room from the drawing method seems to look wrong based on her measurements using this method.

9.2.3 Room 2

Effectiveness

When using the drawing method compared to the camera method in room 2 the participant used 11 minutes and 43 seconds with the drawing method, while when using two attempts for the camera method, the participant used 11 minutes and 25 seconds combined. Meaning, she used 17 seconds less with the camera method, but with two attempts (see Table 30). Additionally, the participant used a total of six breakdowns with the camera method and four breakdowns with the camera method, with the drawing method using 46 seconds longer on breakdowns. However, the score using the drawing method is 5 out of a max score of 20, while the camera method is 13 out of the 20 (see Table 31).

Room 2	Drawing	Camera
Time spent per method	11m 43s	5m 51s
Second attempt		5m 34s
Time spent difference	17s	
Number of breakdowns	6	4
Total time spent on breakdowns	06m 13s	05m 27s

Table 30 Person 2 Room 2 completion overview

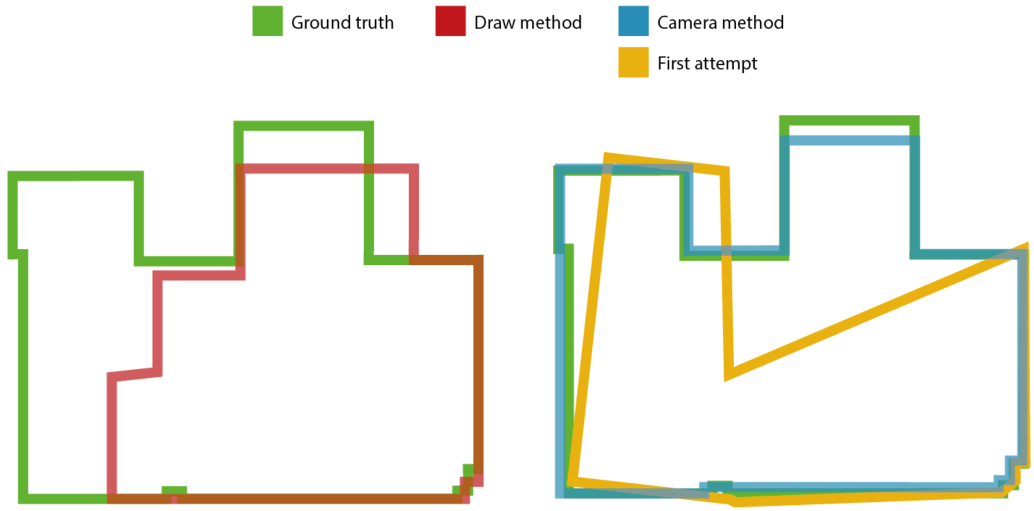

Figure 57 Person 2 Room 2 Output

Person 2 - Room 2

Wall (combined)	Wall	Ground truth (meters)	Ground truth (combined)	Drawing	Score	Camera	Score
	Wall A	4,9m		5,19m	1	4,81m	1
	Wall B	0,26m		0,34m	0	0,3m	1
Wall 1 (A+C+E)	Wall C	0,53m	5,63m	0,42m	1	0,48m	1
	Wall D	0,26m			0	0,28m	1
	Wall E	0,2m			0	0,17m	1
	Wall F	6,53m					
Wall 2 (D+F+H+J) (F+H)	Wall G	0,18m	7,15m			7,24m	1
	Wall H	0,62m		8,43m	1		
Wall 3	Wall I	0,18m				0,16m	0
Wall 3	Wall J	3,26m				3,3m	1
	Wall K	6,01m					
Wall 3 (K+M)	Wall L	0,26m	7,66m	2,75m	0	7,71m	1
	Wall M	1,65m					
Wall 4	Wall N	2,87m		1,13m	0	2,9m	1
Wall 5	Wall O	2,12m			0	2m	1
Wall 6	Wall P	2,68m		2,04m	1	2,62m	1
Wall 7	Wall Q	3,32m		2,62m	1	2,7m	0
Wall 8	Wall R	2,96m		4,02m	0	2,96m	1
Wall 9	Wall S	3,32m		2,24m	0	2,79m	0

Wall 10	Wall T	2,66m	1,59m	0	2,64m	1
Max Score				20		20
Sum score				5		13

Table 31 Person 2 Room 2 score

Learnability timeline

Draw method

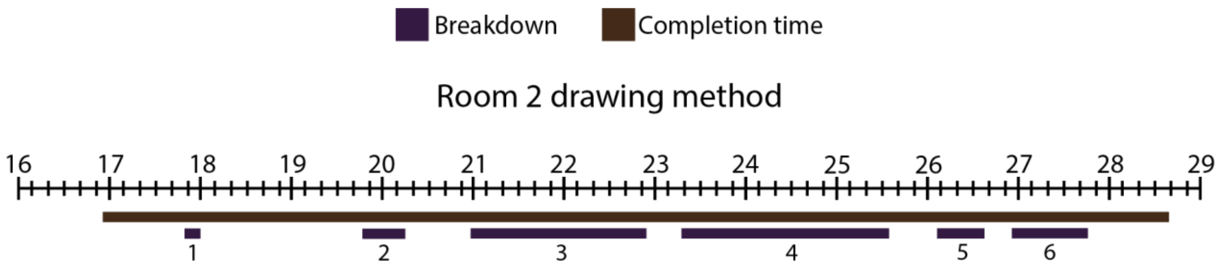

Figure 58 P2 R2 Breakdowns drawing

When she started the drawing method for room 2, she immediately zoomed in to place the first corner point following with the second corner point, creating the first wall. At this point, it seemed that she estimated the length of the first wall by simply looking at it. Once she had placed the first two corner points, she attempted to place more but god confused by the overview.

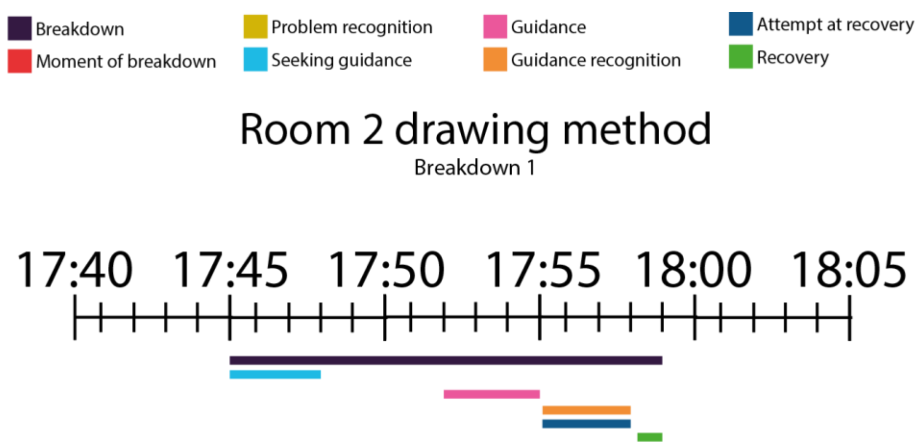

Figure 59 P2 B1 R2 drawing

Breakdown 1 - manoeuvring: She was visibly confused as she attempted to get an overview of the first wall created and ask for guidance. I told her once again to zoom out, which she acknowledged and did.

Between breakdown 1 and 2 she clearly struggled with using the interface efficiently, struggling between zooming in and out, and placing the corner points accurately. She was very hesitant in the way she manoeuvres the interface. It also seemed to be the case that she estimated quite a lot in her measurements.

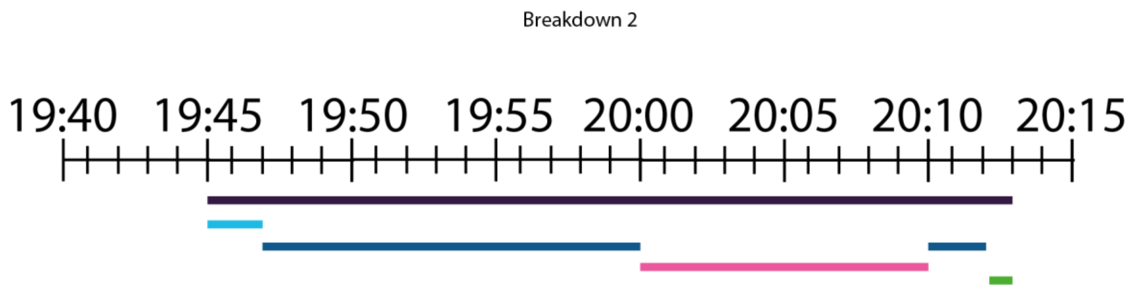

Figure 60 P2 B2 R2 drawing

Breakdown 2 - manoeuvring: When the participant attempted to continue with placing her corner points, she struggled with moving the perspective on the interface so she could place the next corner point. She asked me how she could do this but attempted on her own. Without any success on her own I informed her that she could use two fingers to move the camera perspective on the interface, so she could regain control of the perspective.

As she proceeded to the next corner points, she continued with estimating the lengths of the room, but once she reached a certain point, she struggled with placing new corner points.

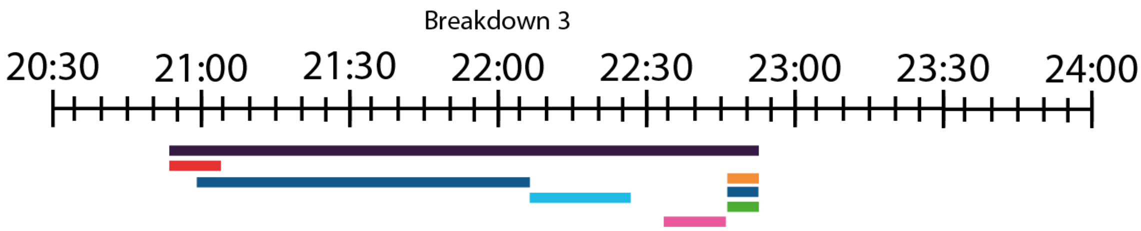

Figure 61 P2 B3 R2 drawing

Breakdown 3 - placing corner points: At this point she fiddled on the interface for quite a while, trying to figure out how to place a corner point. During this, she had zoomed the grid out quite a lot, making it hard for her to place corner points at a detailed location. She attempted this for quite some time, and the program would not recognize her actions when she attempted to place a corner close to existing ones as the interface recognizes this user input as selection of former corner point. This was clearly frustrating for the participant at that point, and she was seeking guidance. But when asking for how to move on, she did not seem to understand the issue as she vaguely tried to explain her goals. She fiddled for a bit longer, but then I informed her to try to tap the screen a bit further away from her original corner point, making the program recognize the user input correctly. I had to be very specific at that point to make sure she understood, but she simply followed the instructions and moved on to successfully place the desired corner point.

It did not take too much time before she encountered the same breakdown.

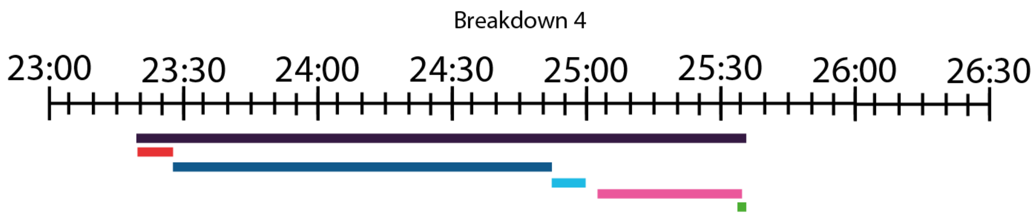

Figure 62 P2 B4 R2 drawing

Breakdown 4 - placing corner points: The same problem as breakdown 3 occurred as the program did not recognize her inputs. This time the informant fiddled around for quite some time, reattempting over and over by pressing the screen, while frustrated and confused to the point she expressed that she was unable to move on. I intervened to try to understand her problem. I informed the participant to try to place the desired corner point at a location further away from her original corner points and then drag them to her desired location. She could then create the corner point by following the advice I gave, and she moved on.

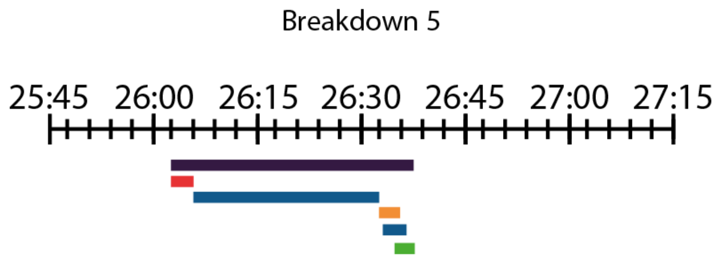

Figure 63 P2 B5 R2 drawing

Breakdown 5 – placing corner points: Once again, she struggled with placing new corner points, and it was clear at that point that she did not understand how to navigate this interface. It was also very visible at that point that she had lost track of the shape of the room. This time she attempted to solve the problem by herself and it looked like she applied the tips I gave in breakdown 4, to place the desired corner point further away and then readjust it, which she succeeded at.

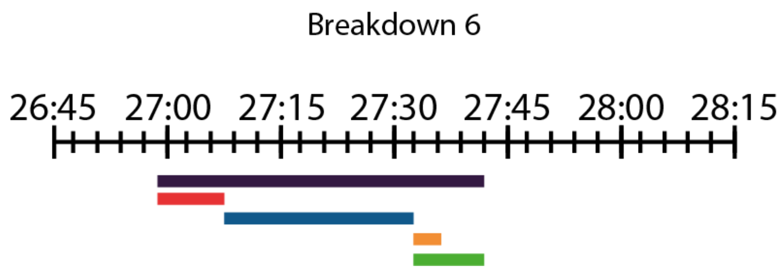

Figure 64 P2 B6 R2 drawing

Breakdown 6 – placing corners and completing drawing: Once the participant reached the final corner, she attempted to create a corner point from a very zoomed out location but still struggled with the same issue as previously. And it was likely that she never understood that the program would select the previous corner points when clicking close to them in a very zoomed out perspective. She attempted over and over to place the corner points at her location, and instead of zooming in to be more accurate, she placed the corner point far away from her location and readjusted it to where she desired, in result completing the drawing at last. She confirmed however during the interview that placing the corner points was indeed a difficult task.

At this point, when the participant has completed the drawing, she recognized that the shape of the room does not resemble the room which can be seen in Figure 57. But visibly frustrated and confused she decided to not fix it and moved on to the next task.

Camera method

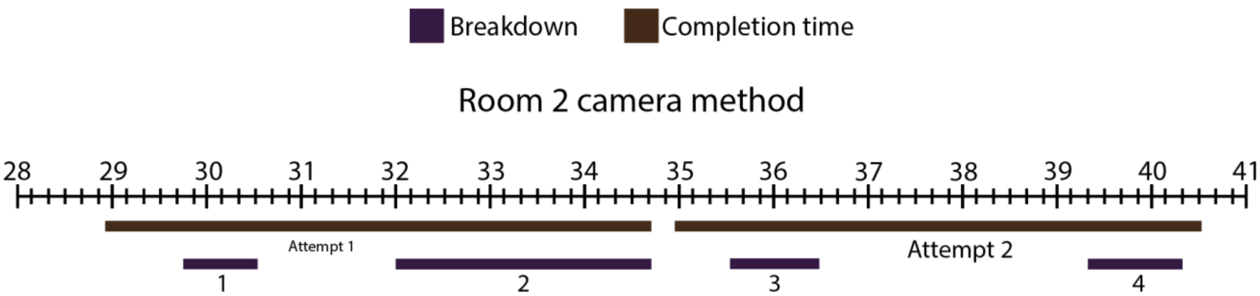

Figure 65 P2 R2 Breakdowns camera

Attempt 1

Once given the task to capture room 2 with the camera method, the participant was quick to begin, with no issues at initializing as the program instantly initialized itself without much user interaction. Once the camera was initialized, the participant directly went towards the first corner of the room and placed the corner point with ease aiming closely to the corner and the ground, then proceeded to the next corner to do the same. When the participant however went on to capture the lower right section of the room (see Figure 57), she faced some issues.

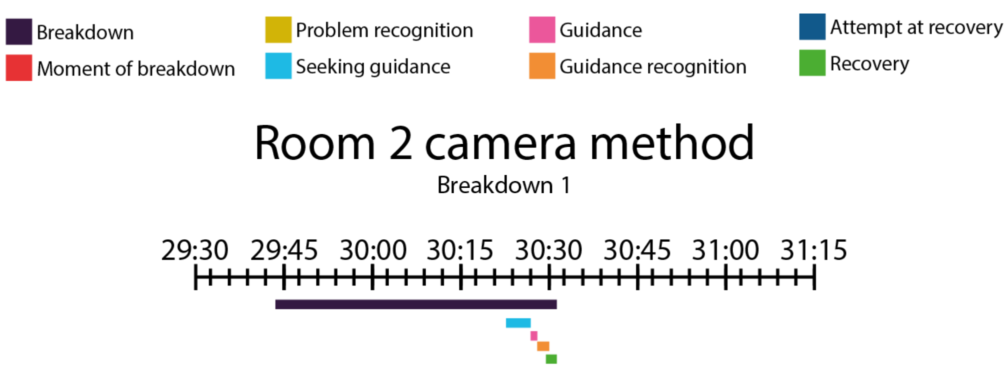

Figure 66 P2 B1 R2 camera

Breakdown 1 – placing and confirming corner: When she attempted to capture the last detail in the lower right section, she attempted for a long time to make the green marker appear, and after a while she asked for help. I recognized that the corner point was registered, but the participant did not. I reassured the participant however that it indeed was registered, and she moved on.

Following breakdown 1, she continued throughout the room, even recognized more details she previously did not see during the drawing method and made sure to capture this. Furthermore, when she encountered more furniture's, she made sure to remove them, and captured the corner points by aiming the camera close to each corner. And at that point, was somewhat efficient at using the interface, until breakdown 2 appeared.

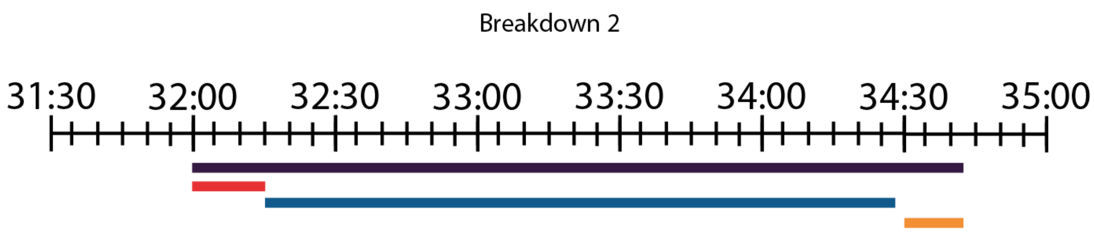

Figure 67 P2 B2 R2 camera

Breakdown 2 – application bug: At this point she was halfway through the room before she managed to lock the phone, resulting in exiting the program. Once she got back into the application, the former corner points made by the participant was altered and both her and me was quite confused. It was decided at this point by the participant and me that it would probably be easier to restart the process, as the output seen in Figure 57 was very affected.

Attempt 2

The start at attempt two was quite like the first attempt, with the participant starting quickly as the camera initialized itself when walking towards the first corner she decided to start at. The participant confirmed the first corner points in the same manner as attempt one, and even stopped at the same corner point for breakdown 3.

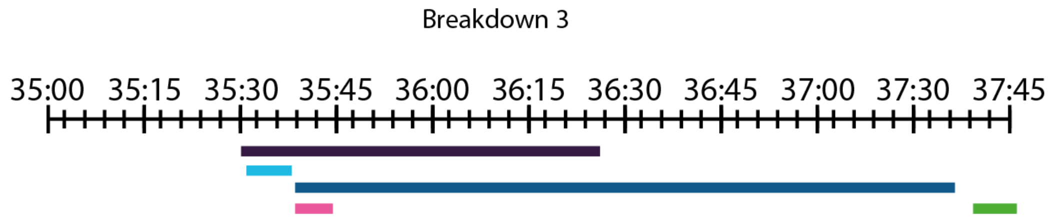

Figure 68 P2 B3 R2 camera

Breakdown 3 – placing and confirming corner: This time, the participant had problems with getting the application to recognize the corner point, the same issue she experienced in breakdown 2 in room 1 of the camera method. She asked me at this point if she could tap the screen herself, in which I replied with a simple yes. This does indicate that she either forgot or did not understand it during the breakdown 2 of room 1. However, she proceeded to tap the screen and continued with scanning the room.

After breakdown 3 however, it would seem the participant had learned, because each time the program did not recognize the corner automatically, she tapped the screen herself. From this point on, she was also rather efficient at using the camera method, walking from corner to corner. She also focussed a lot on capturing the details by moving furniture's on her way. However, once she reached the location with an unmoveable cabinet (wall R), she decides to scan the corner point in front of it and did not address it verbally during the usability test. She continued with the capturing of the room rather quickly after this and connected the corner points with ease.

Figure 69 P2 B4 R2 camera

Breakdown 4 – setting ceiling height: Once she has completed connecting all the corner points, she thought she was finished, and did not respond to the instruction the interface gave. At this point, the interface initiates the "set ceiling height stage", which she had to be reminded of. I told her to aim the camera towards the ceiling, and she seemed confused at this point when aiming the camera upwards and held it still as if she was expecting the interface to recognize the ceiling height automatically. At this point, I redirected her to another corner in thinking that she possibly would realize that she had to tap herself. Shortly after the participant asked if she had to tap the screen, in which I replied yes resulting in successfully capturing the ceiling height.

After the recovery of breakdown 4, the participant decided that she did not need to alter any measurements.

9.2.4 General thoughts from the participant

When asked what method she would prefer, she responded with choosing the camera method, as she felt that it gave her visual cues when she made progress. She did however find it confusing when the visual cues did not appear. She also mentions that she did not like the drawing method, as she found it difficult to navigate.

9.3 Person 3

9.3.1 Basic info

Person 3 was a male at the age close and above 20 years old and rated himself at 5 when using smart phones on the Likert scale, meaning he saw himself as a person who was very confident in using a smart phone. Furthermore, he explained that he had maximum used 1 hour on a drawing application before, but did not clarify what kind, but he explained that he had not used any form of application to capture or measure physical rooms. Like person 1 and 2, he also had used a ruler to measure rooms before.

9.3.2 Room 1

Effectiveness

The participant used 3 minutes and 30 seconds on the drawing method, and 3 minutes and 32 seconds with the camera method, only separated by only 2 seconds. Additionally, the participant experienced two breakdowns (42 seconds combined) with the drawing method and one with the camera method (1 minute and 5 seconds); with the camera method using 23 longer to recover in the breakdowns (see Table 32). However, the participant scored 3 out of the total max score of 8, meanwhile the camera method scored a total of 7 out of the 8 (see Table 33).

Room 1	Drawing	Camera
Time spent per method	3m 30s	3m 32s
Time spent difference	2s	
Number of breakdowns	2	1
Total time spent on breakdowns	42s	1m 5s

Table 32 Person 3 Room 1 completion overview

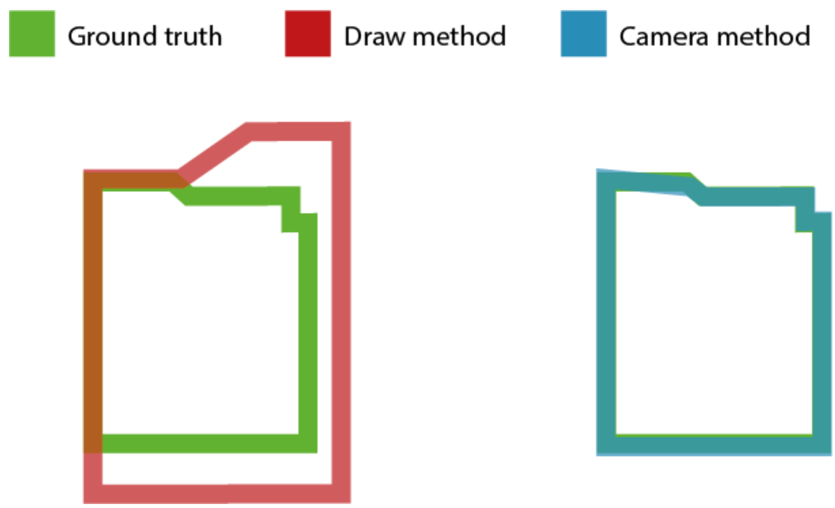

Figure 70 Person 3 Room 1 Output

Person 3 – Room 1

Wall (combined)	Wall	Ground truth (meters)	Ground truth (combined)	Drawing	Score	Camera	Score
Wall A	Wall A	2,57m		3m	1	2,59m	1
Wall B	Wall B	3,17m		3,87m	1	3,23m	1
	Wall C	0,88m		1,07m	1	0,94m	1
	Wall D	0,28m		1,08m	0	0,23m	0
Wall 3 (E+G)	Wall E	1,27m				1,25m	1
	Wall F	0,35m	1,49m	1,05m	0	0,32m	1
	Wall G	0,22m				0,22m	1
Wall 4 (F+H)	Wall H	2,64m	2,99m	4,49m	0	2,69m	1
Max score					8		8

Sum score	3	7

Table 33 Person 3 Room 1 score

Learnability timeline

Draw method

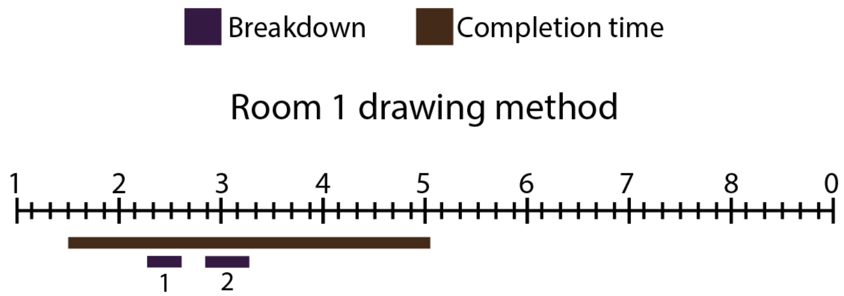

Figure 71 P3 R1 Breakdowns drawing

Before starting, I gave the participant the instructions that 1 meter in real-life equalled one square on the grid, and to navigate he had to use both fingers to zoom in and out. Furthermore, I explained simply that he had to capture the shape of the room by placing corner points that resembled the corner points in the room, and together that would shape the room. This seemed to be understood by the participant, and he immediately started to estimate the first wall based on his own height and recorded the first two corner point.

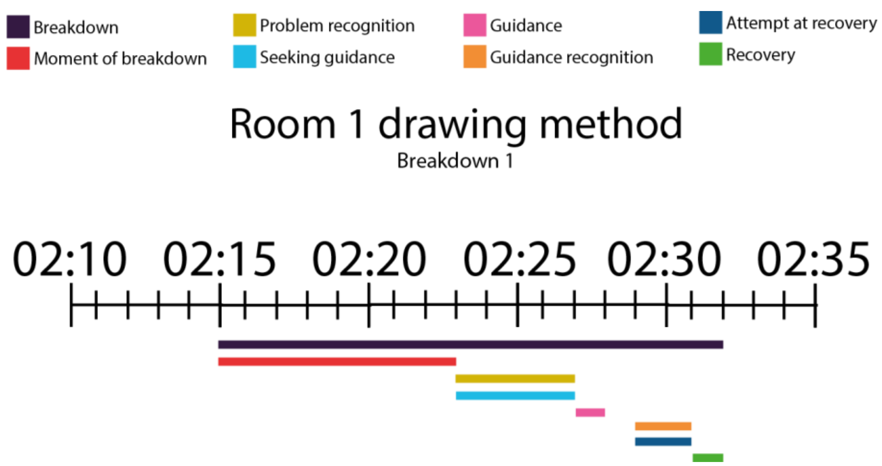

Figure 72 P3 B1 R1 drawing

Breakdown 1 – placing corner points and undo: However, after placing the first two corner points and when he was satisfied with the first wall, he tried to create the next wall based on the first corner point by attempting to click on the first corner point, not realizing that had to continue from the last corner point made. At that point, this was not recognized by me, and he continued with attempting to place corner points. He reached a point where he has created multiple corner points and asked how he could undo the last corner points. I responded with telling him how. He quickly recognizes the guidance and could then start from the initial breakdown point once again.

Between breakdown 1 and 2, he continued to try to place new corner points above the first corner point. This issue explained in breakdown 1, starts breakdown 2.

Figure 73 P3 B2 R1 drawing

Breakdown 2 – placing corner points: This time it seemed that the participant understood that he might had to continue with placing corner points based on the last corner point placed, as he asked this explicitly to me, but in a confused manner. At this point, I replied with that he might give it an attempt, because I was not sure myself. He continued to try it, but quickly realize that it only created another point when attempting to click on the first corner point. From this point out he decided to continue, but it looked like at that point that he attempted to capture the room upside down. This might have led to the inaccuracy seen in Figure 70.

From this point out, it did not look like he had any issues with controlling the user interface, and generally it seemed to be the case that he understood how to navigate it when he created the rest of the room without many problems. Once he completed and entered the finalize stage however he pointed out a few inaccuracies, that he forgot to capture a few details, and it also seemed at this point that he was a bit confused by the fact that the shape did not align with the real-world example, but he expresses that the concept seemed alright to use. One important thing to note is that he might have attempted to fix these issues in the finalize stage if it were not for the fact that I forgot to mention it.

Camera method

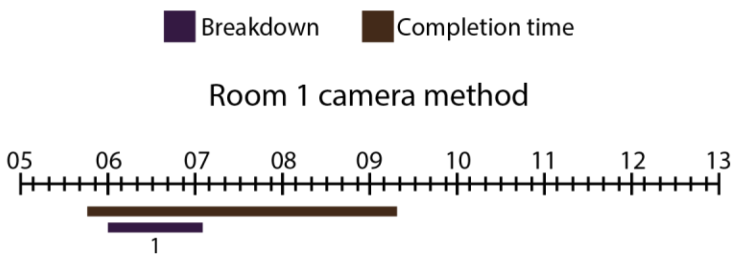

Figure 74 P3 R1 Breakdowns camera

When the participant was met with the same task but with the camera method, I briefly explained to him that to begin with this method, he had to initialize the camera method, which was done by simply moving the camera around the roof to help the camera method recognize the scale of the room. I also tip him to walk outside the room if it did not work. I also explain that once it was initialized, he would be met with a green pole. This was understood by the participant as he attempted to initialize the camera method. But struggled with initializing it.

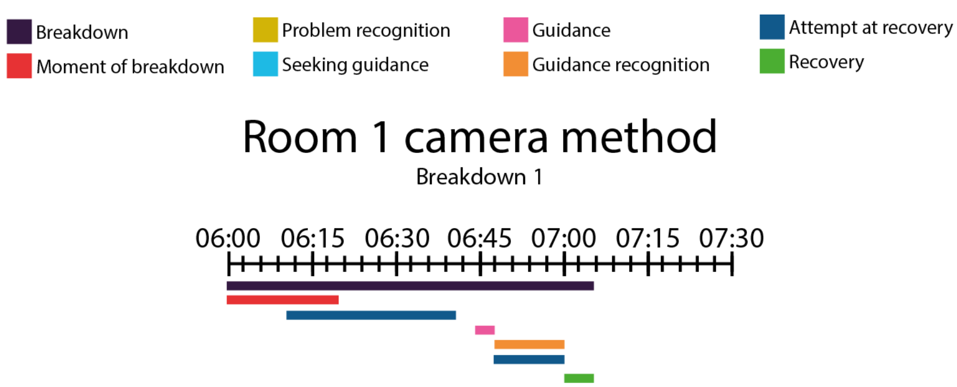

Figure 75 P3 B1 R1 camera

Breakdown 1 – initializing camera method: The participant simply followed the instructions given by me and as he attempted to initialize it, he was given more direct instructions by the application to for instance, “stand still and aim at your feet”, in which he replied to do. This continued for a while during the breakdown, where he simply followed the instructions of the application, and it would not initialize. At this point I tipped him to try and move outside the room and attempt it there, to which he proceeded to acknowledge the guidance and attempted outside the room. As soon as he entered the larger room he was met with the green pole, and it is initialized.

This feedback from the interface was recognized by the participant immediately and walked directly towards a corner. Once he saw the green marker icon he stood still and awaited the corner point to automatically be placed. He understood as soon as he began that he had to place the green pole at each corner point to capture the room and was at this point very quick at capturing the corner points. Once he reached a corner where the program did not automatically confirm the corner point, he simply tapped the screen without any guidance, and it seemed that he recognizes that this is a possibility. Once he had connected all the corner points and entered the set ceiling height stage, he read the feedback given by the application to “point the camera up and tap on the screen to set the room height”, in which he proceeded to understand and do. When he was completed capturing the ceiling height, he quickly asked me if he is done, in which I replied yes.

Once he entered the finalize stage, I explained to him that the measurements could be seen at the side of each wall and explained to him that he can modify its lengths if we want to. He begins to alter some walls but decided that he instead will undo the altercations and decide that he trusted the original measurements made by himself.

9.3.3 Room 2

Effectiveness

Room 2	Drawing	Camera
Time spent per method	13m 16s	2m 42s
Time spent difference	10m 34s	
Number of breakdowns	4	0
Total time spent on breakdowns	4m 54s	0

Table 34 Person 3 Room 2 completion overview

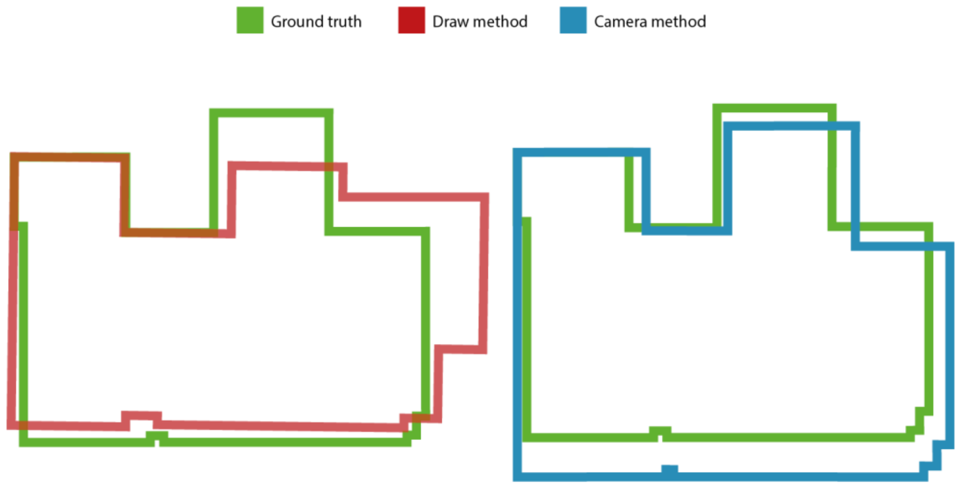

Figure 76 Person 3 Room 2 output

Person 3 - Room 2

Wall (combined)	Wall	Ground truth (meters)	Ground truth (combined)	Drawing	Score	Camera	Score
	Wall A	4,9m		3,98m	1	5,26m	1
	Wall B	0,26m		1,23m	0	0,36m	0
Wall 1 (A+C+E)	Wall C	0,53m	5,63m	1,93m	0	0,59m	1
	Wall D	0,26m		0,94m	0	0,37m	0
	Wall E	0,2m		0,27m	0	0,3m	0
	Wall F	6,53m		6,62m	1	6,17m	1
	Wall G	0,18m		0,25m	0	0,2m	1
Wall 2 (F+H+J)	Wall H	0,62m	10,41m	1,13m	0	0,46m	0
	Wall I	0,18m		0,32m	0	0,21m	0
	Wall J	3,26m		2,94m	1	3,89m	0
	Wall K	6,01m					
Wall 3 (K+M)	Wall L	0,26m	7,66m	7,21m	1	8,76m	1
	Wall M	1,65m					
Wall N	Wall N	2,87m		2,82m	1	3,33m	0
Wall O	Wall O	2,12m		2,07m	1	2,18m	1
Wall P	Wall P	2,68m		3,24m	1	2,53m	1
Wall Q	Wall Q	3,32m		1,89m	0	2,92m	1

(Wall R	Wall R	2,96m	2,84m	1	3,3m	1
Wall S	Wall S	3,32m	0,84m	0	3,34m	1
Wall T	Wall T	2,66m	3,95m	0	2,63m	1
Max Score				20		20
Sum score				8		11

Table 35 Person 3 Room 2 score

Learnability timeline

Draw method

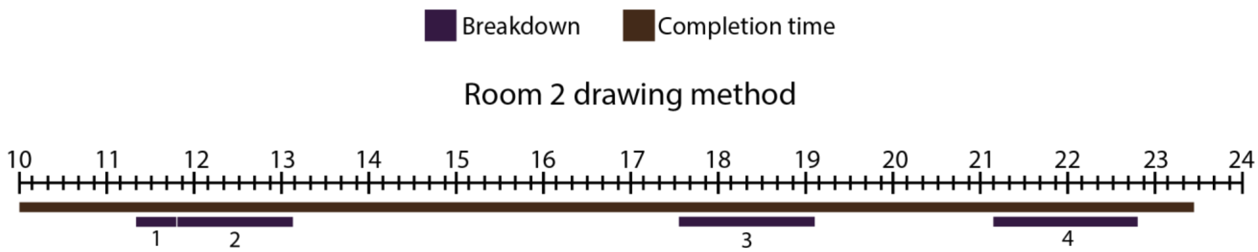

Figure 77 P3 R2 Breakdowns drawing

The participant started by estimating the length of the first wall by simply looking at it, and it did not look like he used any reference point to capture the lengths. But he was quickly creating the first two walls, and as he reached the lower right part of the room, he started to struggle with getting the application to register his inputs.

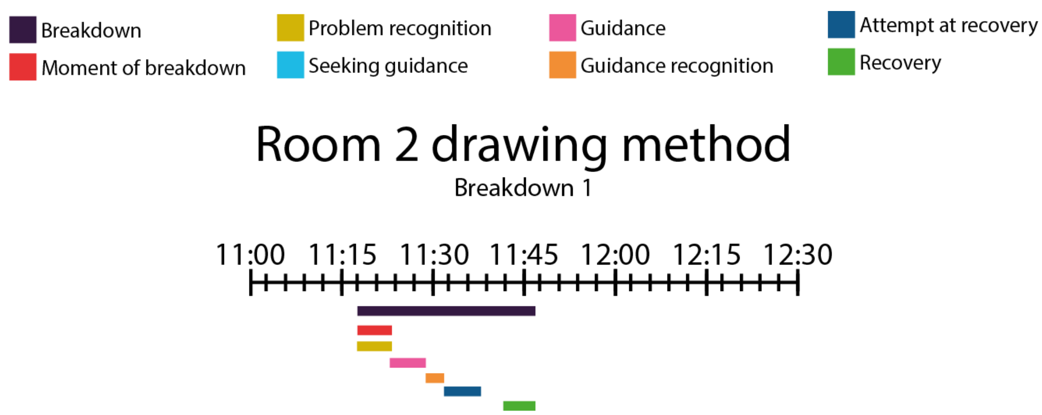

Figure 78 P3 B1 R2 drawing

Breakdown 1 – placing corner points: As he attempted to create a new corner point, he tapped close to the existing one, making the application register the user input as an attempt to adjust the existing corner point. I gave the participant a brief tip to zoom out, place it a bit further away from the original point, then adjust it, to which he understood and proceeded to do.

The duration between breakdowns 1 and 2 were only a few seconds apart, and as soon as it seemed that the participant understood the problem of breakdown 1, he enters breakdown 2 with the same problem.

Figure 79 P3 B2 R2 drawing

Breakdown 2 – placing corner points: when he tried to create the next corner point from the recovery of breakdown 1, the application would not register his desired input, but rather register it as input to target the previous corner point. The participant attempted this a few times until he managed to alter the existing corner point, to which he pressed the undo button, making him remove the corner point made in the recovery of breakdown 1. At this point the participant zoomed out a bit and managed to register a new corner piece, to which he readjusted to the desired location on the grid. At this point he had recreated the corner point he had managed to delete, and again attempted to create the new corner point, but the same problem occurred. At this point, the participant was seeking help to understand why this problem occurred. As he started to explain what was happening, he tried to visualize his problem, but as he was explaining he managed to create a corner point. He verbally recognized at this point that he might have to create the corner point further away from the original position and managed to move on.

From this point, it seemed to be the case that he felt comfortable with using the interface and did not experience many issues when capturing the corner points, but he was placing all the corner points at a rapid pace at this point. However, he experienced a few times, similar issues occurred on breakdown 2, but it seemed at this point that he understood that he had to be assertive with the position of the corner point he had created the. Also, from this point he very quick at estimating the lengths of each wall, indicating that he did not give much attention it if the measurements are correct or not. This seemed to be the case when examining Figure 76.

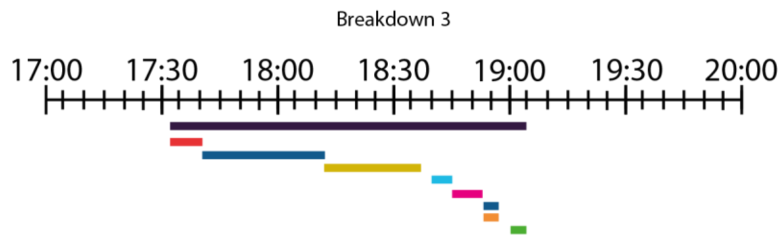

Figure 80 P3 B3 R2 drawing

Breakdown 3 – placing corner points: When the participant reached the left corner in the top of the room, he experienced the same problem as previously. This time, he tried to create a new corner point that would be placed inwards towards the room, to which he experienced that the application registered as input to target other corner points. He attempted for a while but ended up seeking guidance once again. He recognized the problem by explaining what he wanted to achieve, but the application did not register it. I suggested that he might try to place the corner point opposite way from the room and adjust it to the position he wants. He recognized this and proceeded to adjust it to his position.

Based on the observations at that point, the participant did not experience any problems and was generally quick at placing the corner points. He did not however seem to focus on the measurements at that point either and it did not seem to concern him either, but rather on capturing the shape of the room.

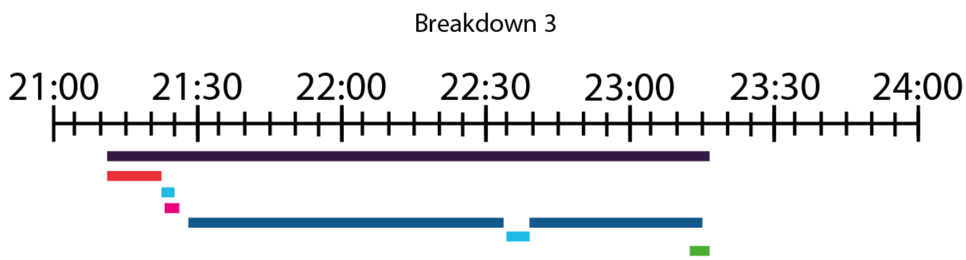

Figure 81 P3 B4 R2 drawing

Breakdown 4 – completing drawing: When attempting to connect the corner points, the participant attempted to drag the current corner point on top of the first corner point in hopes of finishing the shape of the room. However, he did not understand that he had to tap at the first corner point to finish the drawing.

At this point he asked me if what he was doing was correct, to which I replied yes, believing at the time that it should be enough. But in hindsight, now understanding that it does not work. He therefore attempted at this for a while, hoping the interface would automatically connect the corner points until he needed help once again, but before I gave any suggestions, he pressed the exit screen. When doing so the application would connect the last corner pieces, and he managed to complete the drawing.

When being asked to alter the measurements, he only adjusted one wall, and seemed to trust his own judgement on the capturing of the room. He decided rather quickly that his measurements were correct without investigating carefully.

Camera method

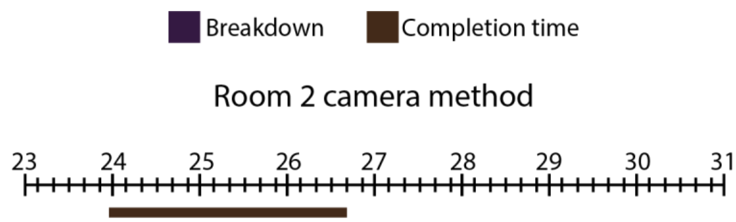

Figure 82 P3 R2 Breakdowns camera

Once the participant had begun with the objective of capturing room 2 with the camera method, he instantly attempted to initialize the camera by simply following the instructions once again, and at this time it started immediately. He proceeded to instantly go towards the corner and waited for the application to automatically register, which it did. Once he reached the lower right of the room, he noted that, “maybe I should try to get this appropriately”, following with him walking towards it, but still standing from a bit of a distance. He is rather quick at capturing this part of the room, and light objects such as chair in the way does not seem to concern him, and generally seemed to be the case that he trusted the automatically placed corner points. Generally, throughout the capturing of the room he seemed to trust the fact that the application attempted to register the corner automatically, resulting in him standing at quite a distance. In doing this, he aimed the camera towards each corner, even if the corner had objects in front of it. If the application registered a corner automatically, the participant moved on.

During the whole capturing, the participant did not experience a single breakdown, and were generally comfortable with using the interface. And it seemed to be the case that he put a lot of faith in that the automatically corner points were registered accurately even though him standing from a distance, an object would obscure it or even both. If it was automatically captured, he moved on. Once he reached the setting ceiling height stage, he did not experience any issue, and followed the instructions and completed the capturing of the room.

Once reaching the finalize stage, the participant simply expressed, “I am happy with the result”, and did not adjust any of the measurements.

9.3.4 General thoughts from the participant

During the interview, the participant began explaining that he believed the drawing method seemed in principle decent to control but felt that sometimes it was hard to create certain corner points at times, and therefore felt it as not being as optimal as it should. Furthermore, he moved on to saying that if it were the fact that the measurements had to be very accurate, he would then find the method unsuitable, as it was hard for him to estimate certain lengths without any tools other than the application.

When explaining his experience with the camera method, he proceeded to say that it was easier to use as it was not only faster, but he also did not have to think about the measurements, saying that he did not doubt himself that much, even though he was unsure whether that would be accurate even. He mentioned also that sometimes after he confirmed a corner point and moved on to the next, he would notice that it looked like the former corner point had moved. This however did not concern him, as he believed that it was easy for him to readjust or remove that corner point and fix it.

10 Group 2

As explained in group 1, this group will start with the opposite method as group 1. Meaning, the participants in this group will begin with using the camera method before the drawing method.

10.1 Person 4

10.1.1 Basic info

Person 4 was a female close to the age of 30. When asked how she would rate herself using a smart phone, she said “3, maybe 4”. The participant also mentioned that she had used a drawing application before, but not comparably, to what the drawing method aimed to achieve. She had however used an application before, for measuring lengths of walls. She explained it as a digital ruler, which she did claimed did not work at all.

10.1.2 Room 1

Effectiveness

The participant used 4 minutes and 40 seconds to complete the task with the drawing method compared to the camera method, using 2 minutes and 43 seconds, with 1 minute and 57 seconds separating the two. With both methods, the participant experienced three breakdowns; however, 2 minutes and 4 seconds longer to resolve with the drawing method (see Table 36). Furthermore, the participant scored 6 points out of a total max score of 8 with both methods (see Table 37). Both points lost, were lost on wall sections with small details. One thing to note is that, when using the drawing method, the participant missed the accurate measurement on wall D with 16cm, and wall G with 32cm, meanwhile the camera method missed wall D with only 5cm, and wall G with 5cm.

Room 1	Drawing	Camera
Time spent per method	4m 40s	2m 43s
Time spent difference	1m 57s	
Number of breakdowns	3	3
Total time spent on breakdowns	3m 19s	1m 15s

Table 36 Person 4 room 1 completion overview

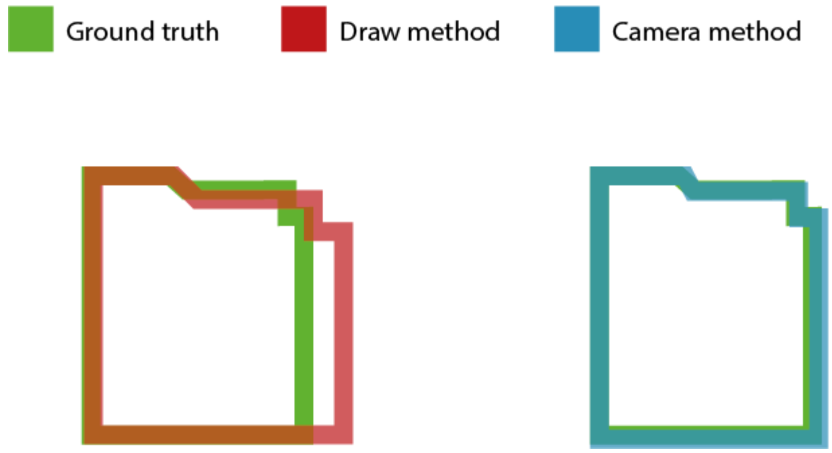

Figure 83 Person 4 Room 1 Output

Person 4 - Room 1

Wall	Ground truth (meters)	Drawing	Score	Camera	Score
Wall A	2,57m	3,07m	1	2,66m	1
Wall B	3,17m	3,17m	1	3,23m	1
Wall C	0,88m	0,9m	1	0,93m	1
Wall D	0,28m	0,44m	0	0,23m	0
Wall E	1,27m	1,46m	1	1,35m	1
Wall F	0,35m	0,43m	1	0,35m	1
Wall G	0,22m	0,4m	0	0,27m	0
Wall H	2,64m	2,43m	1	2,67m	1

Max score			8		8
Sum score			6		6

Table 37 Person 1 Room 1 score

Learnability timeline

Camera method

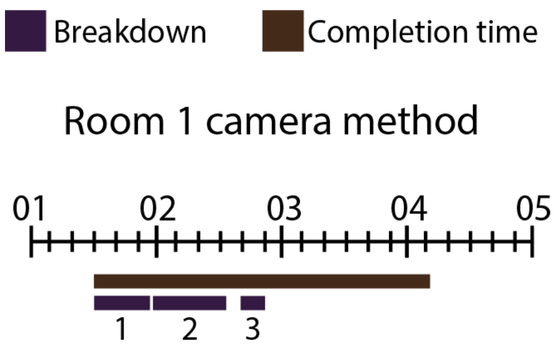

Figure 84 P4 R1 Breakdowns camera

During the introduction to the method, the participant was explained that the objective was to capture the room using two methods, starting first with the camera method. First, I explained that to initialize the camera method she had to aim the camera around the room and follow the instructions.

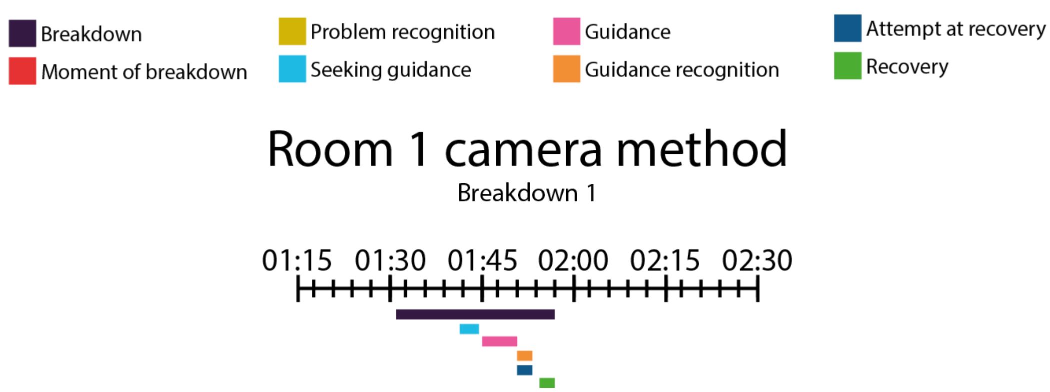

Figure 85 P4 B1 R1 camera

Breakdown 1 – initializing camera method: When the participant attempted to initialize the method, she struggled to get it started, and asked if she should follow the instructions of the application. To which I replied to, "if it does not respond, try to aim it towards the bigger room (room 2)". She recognized the help and began to aim at the larger room. Once the green pole appeared, I pointed out that she could now begin.

Before breakdown 2, it is important to note that, at this point, when the green pole appeared, I did not mention how she was supposed to use the method, because she instantly attempted to do it by herself.

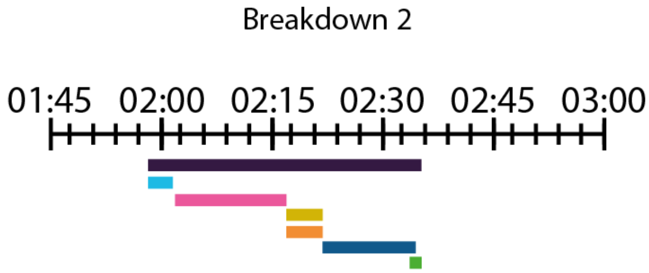

Figure 86 P4 B2 R1 camera

Breakdown 2 – placing and confirming corners: When the participant began attempting to capture the room, she asked if she was supposed to follow the floor, to which I replied with: "yes, every corner". She went on to try to capture the first corner point by aiming at it. Before the green confirmation circle had been completed, she moved on to the next corner. This meant that at this point, no corner point had been placed, and it looked like that she though that it was recorded. I went on to tell her that she had to hold it still at each corner point. She went on to capture her first corner piece, then understood the point by verbally telling me: "okey, so the goal is to record one point, then stretch it to the next!", which I confirmed.

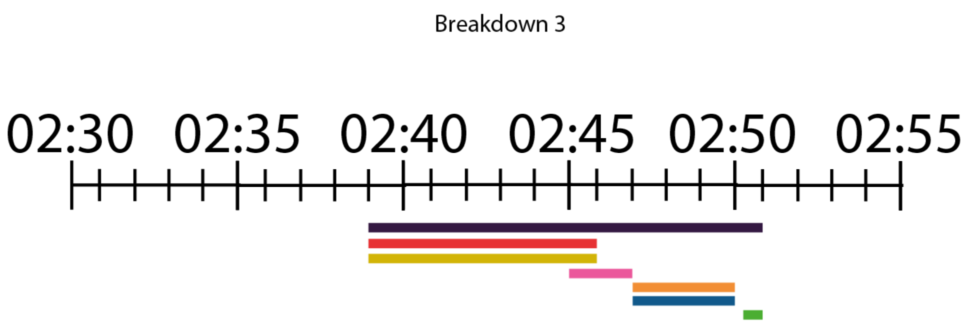

Figure 87 P4 B3 R1 camera

Breakdown 3 –confirming corners: When the participant arrived at the angled wall, the application would not automatically place the corner point, to which she became a bit confused. I simply told her that she could tap the screen to record it herself. She proceeded to do this rather quick.

To this point, she had created 1/3 of the room by standing still, once she had reached the top right of the room she asked if she could be as accurate as possible, to which I replied with yes, and that she probably could move a bit closer to the corner points. When the participant had recorded the top right part of the room, she had reached the corner with the shelves. At this stage she asked if this mattered, but before me giving any feedback, she aimed towards the corner and the application recorded the corner point automatically.

When the participant reached the entrance of the room, she became a bit confused if she should record the entrance or not, but I told her to only focus on the walls, which I had forgotten to mention. She proceeded to connect all the corner points without any problems and entered the setting ceiling height stage to which she instantly followed the instructions of the application successfully. When reaching the finalize stage, I explained that she could now alter the measurements if she wanted to do so, to which she replied with that she was satisfied with the results.

Draw method

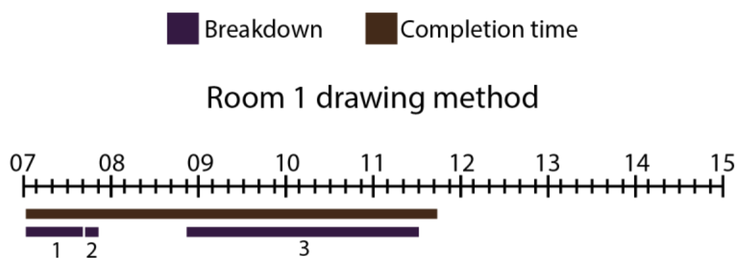

Figure 88 P4 R1 Breakdowns drawing

Before the participant began with the drawing method, I explained to her that in this method, the objective was to tap the screen for each corner point to draw a wall. I then mentioned that one square on the grid was 1 meter in real-life, and to zoom in and out, she had to use her fingers. Before she began, she asked if she should place a corner point, then drag that point forwards, or if she should place a new corner point to create a wall, to which I replied that the latter was correct. This was understood, and she moved her corner point to a corner of a square to make sure she starts at a good position.

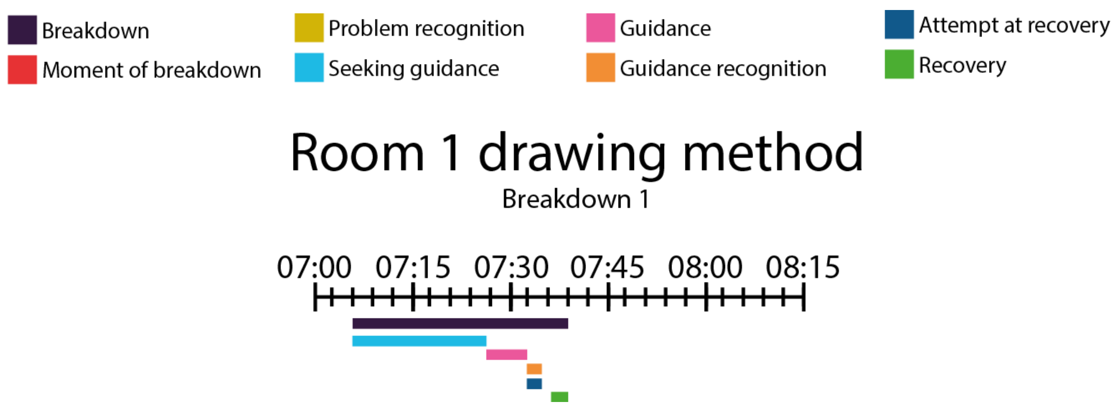

Figure 89 P4 B1 R1 drawing

Breakdown 1 – adjusting corners: Once the participant had created her two first corner points, she was a bit confused as to how she could adjust this corner point to where she wanted it to be placed in terms of accuracy it seems. I explained that she had to press the arrow until it is green, and then she could adjust it. To which she replied, “I understand”, and proceeded to adjust the corner point.

Figure 90 P4 B2 R1 drawing

Breakdown 2 – understanding the concept: Shortly after the first breakdown, she asked if she now after placing the first two corner pieces were supposed to continue with the procedure until the shape is complete. I confirmed this, she understood and proceeded to draw the shape of the room.

As soon breakdown 2 was recovered, she recorded the corner pieces very fast, but it did not look like she focused too much on the accuracy at this point. She simply skipped the extra corners in the top right corners and did not seem to be the case that she measures the length in any way, but more focused on finishing.

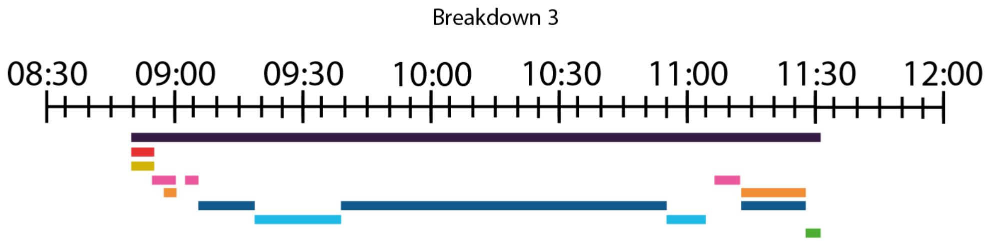

Figure 91 P4 B3 R1 drawing

Breakdown 3 – finalizing drawing: When she entered the finalize stage, she began to show me that she was finished, but in the process, she discovered that she had forgotten the corner points on the top right corner of the room. I reassured to her that in this stage she could adjust and add corner points if she wanted to. She decided to attempt to fix this corner of the room. She first attempted to click on the add corner button, but since she had zoomed the perspective out quite a bit, it did not look like she recognized that a corner piece had appeared since it appeared close to an existing one. She fiddles with the interface for a bit, until she decided to ask me specifically how she could create a new corner point, but before I begin to highlight, she decided to attempt it once again. This time she created the new corner point, but she had to adjust them into position this time. She fiddles with this for a while, visibly struggling and slightly confused about how she can achieve the capturing of the details. After a while, she completed almost all the adjustments, but in the process, an unwanted corner point had occurred. She asked me how she could remove this, to which I explained that if she would readjust the current corner piece, so it aligns with an existing one, it would disappear. She understood this and were able to remove it, finishing the shape of the room in the process.

During all this, she never mentioned the actual measurements of the actual room or use any method to capture the measurements.

10.1.3 Room 2

Effectiveness

The participant used 6 minutes and 52 seconds to complete the task with the drawing method, compared to the camera method with two attempts, at a combined duration of 16 minutes and 24 seconds, separating the two methods with 9 minutes and 32 seconds (see Table 38). The participant also experienced three breakdowns for both methods but using 7 minutes and 34 seconds longer to resolve the breakdowns on the camera method. The participant also scored better using the drawing method, with 14 points out of max 20 points; meanwhile, the camera method scored only 7 points (see Table 39).

Room 2	Drawing	Camera
Time spent per method	6m 52s	3m 30s
Second attempt		12m 54s
Time spent difference	09m 32s	
Number of breakdowns	3	3
Total time spent on breakdowns	1m 18s	8m 52s

Table 38 Person 4 room 2 completion overview

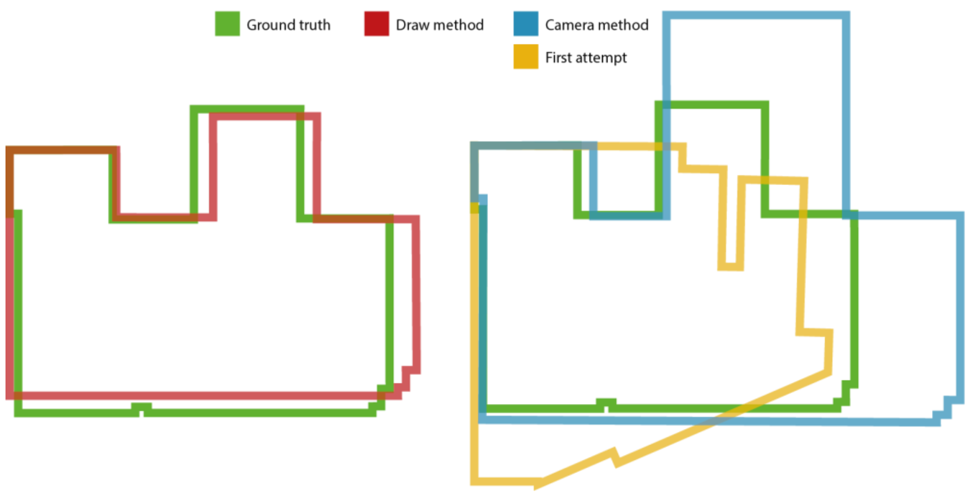

Figure 92 Person 4 Room 2 Output

Person 4 - Room 2

Wall	Wall	Ground truth (meters)	Ground truth (combined)	Drawing	Score	Camera	Score
	Wall A	4,9m		4,3m	1	5,3m	1
	Wall B	0,26m		0,32m	1	0,38m	0
Wall 1 (A+C+E)	Wall C	0,53m	5,63m	0,52m	1	0,45m	1
	Wall D	0,26m		0,24m	1	0,33m	0
	Wall E	0,2m		0,25m	1	0,23m	1

Wall 2 (F+H+J)	Wall F	6,53m	10,41m	11,46m	1	13,45m	0
	Wall G	0,18m					
	Wall H	0,62m					
	Wall I	0,18m					
	Wall J	3,26m					
Wall 3 (K+M)	Wall K	6,01m	7,66m	7,15m	1	6,67m	1
	Wall L	0,26m				0,27m	1
	Wall M	1,65m				1,34m	0
Wall N	Wall N	2,87m		2,96m	1	3,34m	0
Wall O	Wall O	2,12m		2,03m	1	2,13m	1
Wall P	Wall P	2,68m		3,17m	1	2,46m	1
Wall Q	Wall Q	3,32m		3,04m	1	6,06m	0
Wall R	Wall R	2,96m		2,88m	1	5,17m	0
Wall S	Wall S	3,32m		3,1m	1	6,04m	0
Wall T	Wall T	2,66m		2,98m	1	3,44m	0
Max Score					20		20
Sum score					14		7

Table 39 Person 4 Room 2 score

Learnability timeline

Camera method

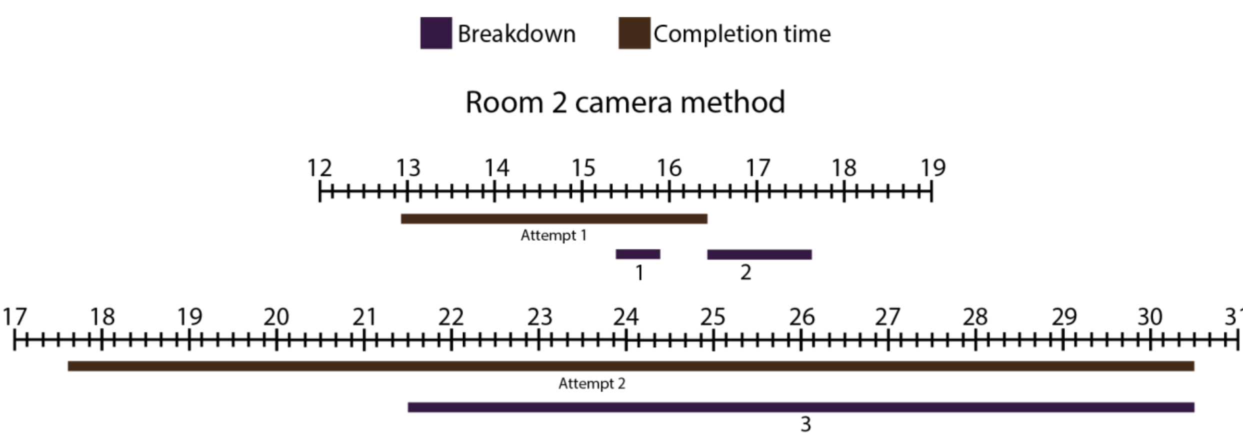

Figure 93 P4 R2 Breakdowns camera

Attempt 1

When starting the camera method on room 2, the participant did not experience any issues when initializing the camera method, nor did she experience any issues when recording the first corner point. Up until breakdown 1, the participant was rather quick at placing each camera point, but she did place each corner point from a distance, indicating that she trusted the automatically placed corner points.

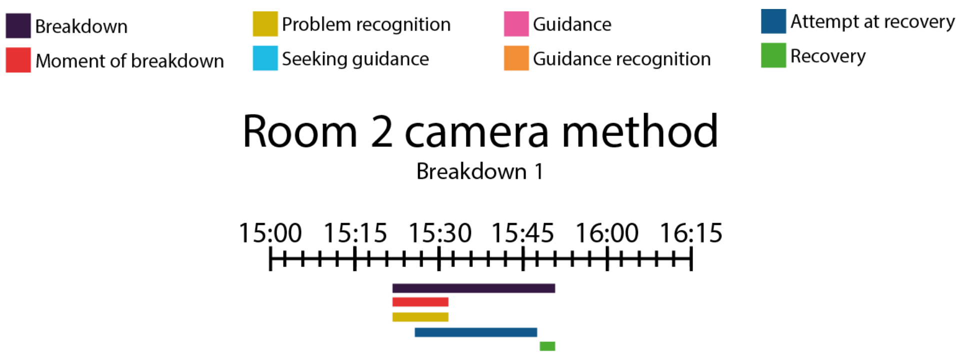

Figure 94 P4 B1 R2 camera

Breakdown 1 – placing and confirming corners: Once the participant reached the point where she had to scan the corners in front of the cabinets, she recognized that at this point she would have to guess, by placing the corner points through the cabinets, placing it at a random location behind. At the time, it looked fine, and she moves on.

Following, she did have a slight problem understanding if she had connected the points or not, but this was resolved very quick by herself. In addition, when she reached the setting ceiling height stage, she remembered how this was achieved the last time, and proceeded to set the height instantly.

In between attempt 1 and 2

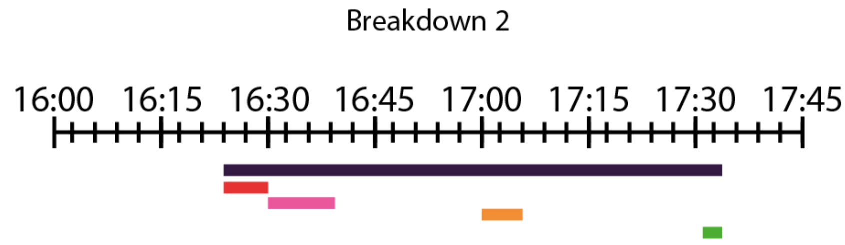

Figure 95 P4 B2 R2 camera

Breakdown 2 – retrying the task: However, once she reached the finalize stage, the outcome was presented to the participant. When looking at Figure 92 some error had to have occurred, and this was very much recognized by the participant during the usability test. As she laughed about the outcome, she attempted to understand what went wrong, analysing where the error might have occurred, but she was confused. I decided to recommend the participant to maybe retry the objective with the same method, to which she agreed.

Attempt 2

This time, when the participant began to capture the shape of the room, she expressed that maybe she should try to get a bit closer to the corner points. Moreover, it seemed to be the case that she understood that she had to be more assertive of where the corner points were placed, and maybe the automatically placed corner points were not as accurate as she thought. When met with furniture's, she decided this time to move them, to get closer. When finishing 2/3 of the room, it was observed that she scanned each corner point much closer than previous.

When reaching the same location with the cabinets, she decided to guess as she did during breakdown 1. This time, it was seen during the analysis that she aimed much further away than the real-world corner point was located, but this did not seem to be understood by the participant at the time. When she was about to connect the corner points, she realized that the corner points did not add up, and in hindsight, it seemed to be the result of the "guessed" corner points that caused this problem. She decided that this was something that she might be able to adjust during the finalize stage.

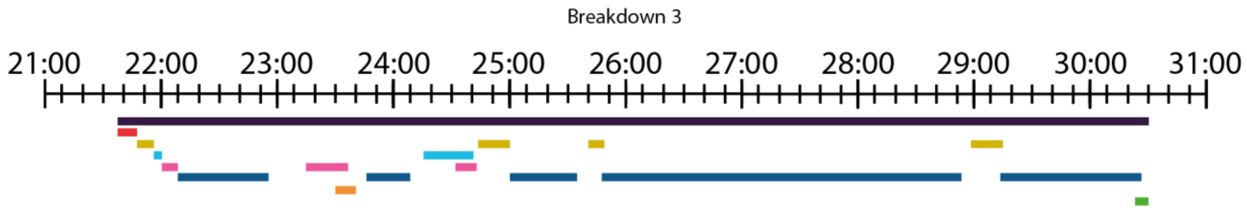

Figure 96 P4 B3 R2 camera

Breakdown 3 – fixing original measurements: Entering the finalize stage, the participant was very confused and understood that an error must have had occurred. When looking at the drawing, the participant was confused when one of the last corner points was placed at an inaccurate location. This was the location where she decided to guess. However, during the usability test, this did not seem to be understood by the participant, as she was confused when trying to place herself in the drawing. She did ask however if she can now adjust this corner, and how this was achieved. She began with adjusting the wall that is inaccurate by joining that wall with an existing one, causing more confusion. In hindsight, what she probably should have done at this point was to adjust the corner points that are located behind the cabinets. Instead, after she had joined the two walls, she was confused as to why the shape did not resemble the real-world room. At this point I decide to recommend the participant to undo her actions, to get her back at the point where the breakdown started. She proceeded to do so, but she joined the two walls together once again, creating the large section in the top right on Figure 92 at her second attempt. At this point she realized that she was missing one wall and decided to extend the wall on the right seen on Figure 92 creating a wider floorplan in the process. This results in her having to readjust the corner pieces in the lower right section of the room as well. This did not seem to make her question if she was doing the right thing or not, but rather happy when she had completed the shape of the room. Before deciding to finish, she also recognized that she is missing the minor indent on the top left corner of the room, and she decided to fix this.

Draw method

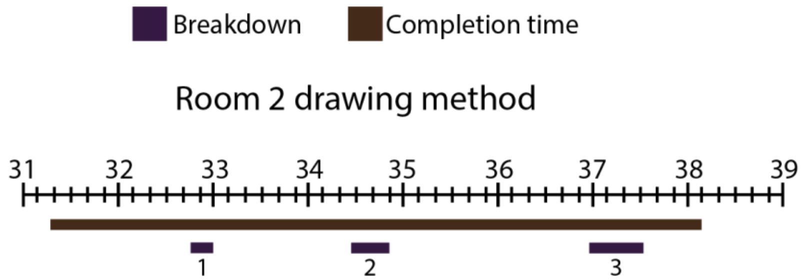

Figure 97 P4 R2 Breakdowns drawing

When starting the drawing method, the participant noted that she was doubting whether she was going to be able to capture the real-world measurements but began adding corner points without many issues. As she added the first three corners she arrived at the location with the cabinets (wall R), where at this point, she had just estimated the lengths of wall based on own intuition it seemed. It was never recorded the thought process at this point, but no observable methods were used to capture the lengths.

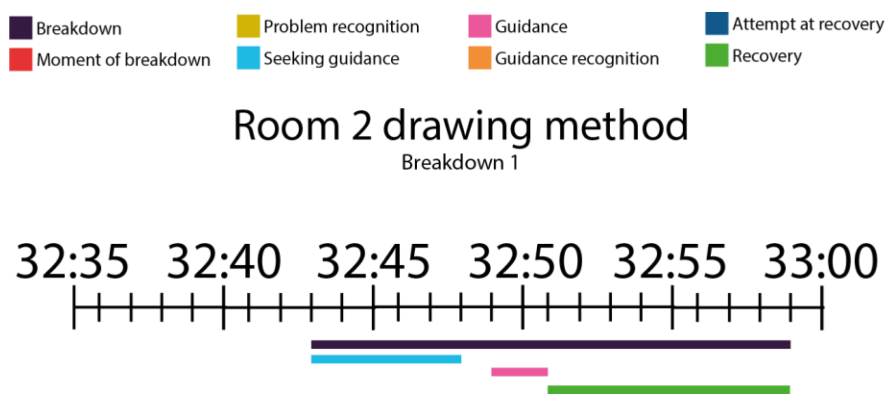

Figure 98 P4 B1 R2 drawing

Breakdown 1 – manoeuvring the interface: Before continuing she asked for help for how she could move the position on the grid, because when she tried, she only moved the current corner point. I explained that she had to use two fingers and drag the perspective the way she wanted.

From this point and on, she sat in the middle of the room and created the room from this location. She did not struggle much with placing corner points at this stage, and generally was good at using the interface.

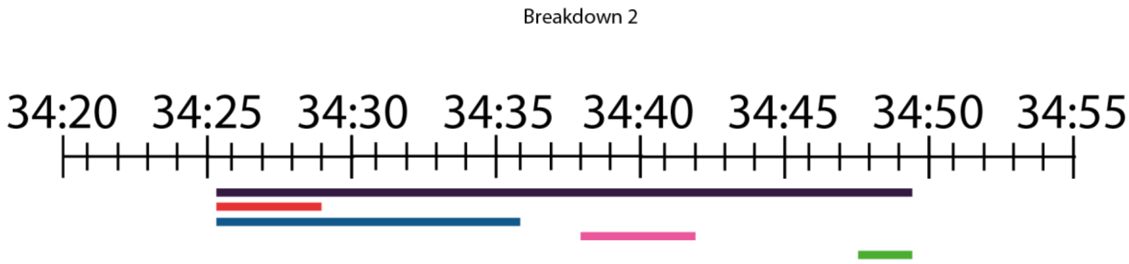

Figure 99 P4 B2 R2 drawing

Breakdown 2 – placing corners: However, when she had to create corner points that were close to the original ones, the application would not register the user input, making the participant frustrated. I recommended to try tapping the screen further away from the original point, to which she attempted to do so. After a few tries, clicking further and further away she succeeded.

It looked like the participant had learned from breakdown 2, as she successfully created new corner points when she encountered the same problem. She was as previously still sitting in the middle of the room at this point.

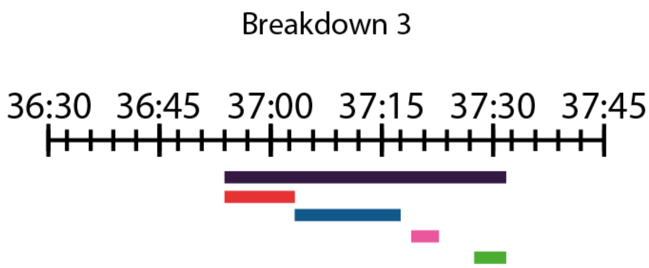

Figure 100 P4 B3 R2 drawing

Breakdown 3 – confirming drawing: When attempting to complete the drawing, the participant seemed to forget that all she had to do was tap the last corner point, but instead tried to align her last corner point on top of the first corner point. I recommend aligning it as close as possible then press the exit button. She proceeded to follow this advice and successfully connected the corner pieces entering the finalize stage.

Once she reached the finalize stage, she only adjusted one wall as it was a bit skewed but decided rather quick that she was satisfied with the result and did not want to readjust any measurements.

10.1.4 General thoughts from the participant

The participants found the camera method to be an efficient tool for capturing rooms but thought that a certain learning curve had to be achieved. She expressed during the interview that for instance, she learned that she had to be more precise with her placement of the corner points with the camera method, as she experienced the application to not be as accurate as she immediately thought. She also stated that even though the camera method automatically placed corner points for her, she thought that those placements were both positive and negative. She also expressed that she did not feel that she mastered this method by any way, but with a bit more training, she would be very comfortable with using it. One thing the participant expressed as a concern and frustration was when there were objects obstructing the corner, as she did not know what to do at that point.

However, when discussing the drawing method, the participant stated that she felt more in control compared to the camera method, as the end-result became more accurate and that she did not have to adjust as much as she had to during the camera method. She felt that she had to “fix” more problems when using the camera method. Even though she expressed that she felt it became more accurate with the drawing method, she was concerned with the fact that perhaps the camera method could measure the measurements more accurately than her own assumptions of the lengths and stating that a tool for measuring the lengths as a substitute for the drawing method would be of good use. In general, the participant stated that she felt that the interface was easy to use but had some issues with adjusting the corners in the finalize stage, as she felt that the application would not respond so well sometimes with her actions.

10.2 Person 5

10.2.1 Basic info

Person 5 was a female at the age close and above 30 years old, rating herself as a 4.5 at the Likert scale. The participant said she had some previous experience with applications to measure lengths of rooms, which she stated was like the camera method, regarding placing a corner piece, then dragging a wall to measure lengths.

10.2.2 Room 1

Effectiveness

This participant used 2 minutes and 57 seconds to complete the task with the drawing method, while with the camera method; the participant used two attempts with a total of 5 minutes and 10 seconds to complete. Additionally, the participant experienced only one breakdown with the drawing method, and two in the camera method, using 1 minute and 20 seconds longer to resolve the breakdowns compared to the drawing method (see Table 40). Furthermore, the participant scored 7 out of maximum 8 using the drawing method, and 8 out of 8 using the camera method (see Table 41). Even though the camera method scored 8 out of 8, when inspecting Figure 101, it can be examined that wall E was misaligned, causing the rest of the room shape to also be misaligned.

Room 1	Drawing	Camera
Time spent per method	2m 57s	4m 2s
Second attempt		1m 8s
Time spent difference	2m 12s	
Number of breakdowns	1	2
Total time spent on breakdowns	58s	2m 18s

Table 40 Person 5 Room 1 completion overview

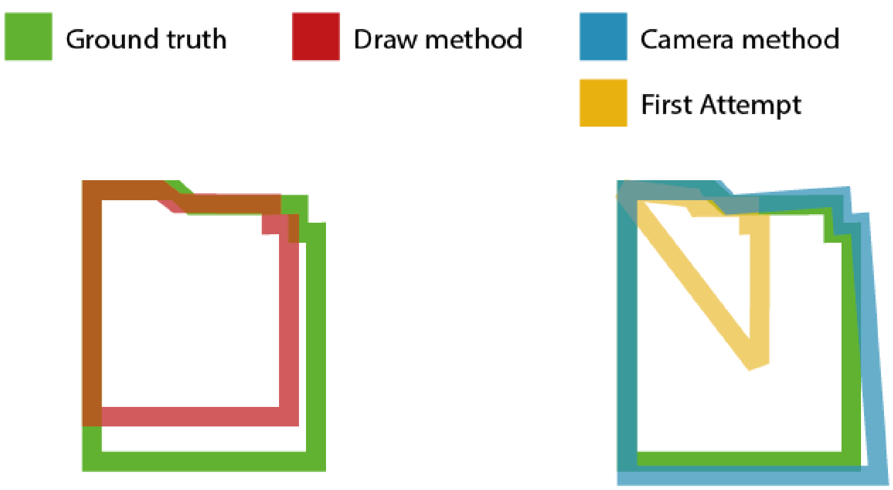

Figure 101 Person 5 Room 1 Output

Person 5 - Room 1

Wall	Ground truth (meters)	Drawing	Score	Camera	Score
Wall A	2,57m	2,23m	1	2,91m	1
Wall B	3,17m	2,6m	1	3,35m	1
Wall C	0,88m	0,69m	1	0,95m	1
Wall D	0,28m	0,27m	1	0,26m	1
Wall E	1,27m	1,11m	1	1,33m	1
Wall F	0,35m	0,26m	0	0,35m	1
Wall G	0,22m	0,22m	1	0,22	1
Wall H	2,64m	2,18m	1	2,93	1
Max score			8		8
Sum score			7		8

Table 41 Person 5 room 1 score

Learnability timeline

Camera method

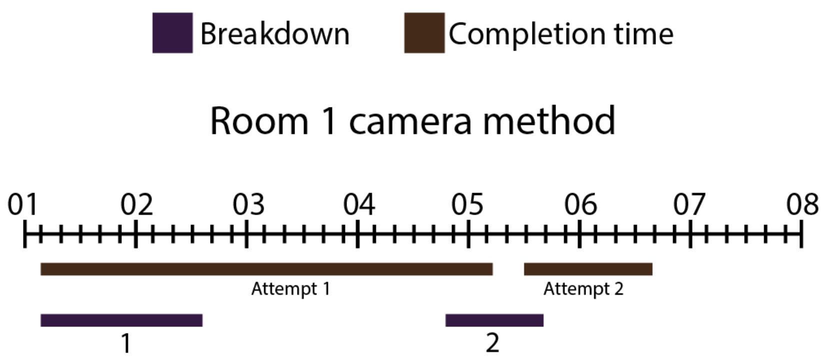

Figure 102 P5 R1 Breakdowns camera

Attempt 1

Before the participant began the usability test, I gave the instructions that before using the camera method, she had to initialize it by scanning the room to make sure it understands the heights and lengths, and to follow the instructions of the application.

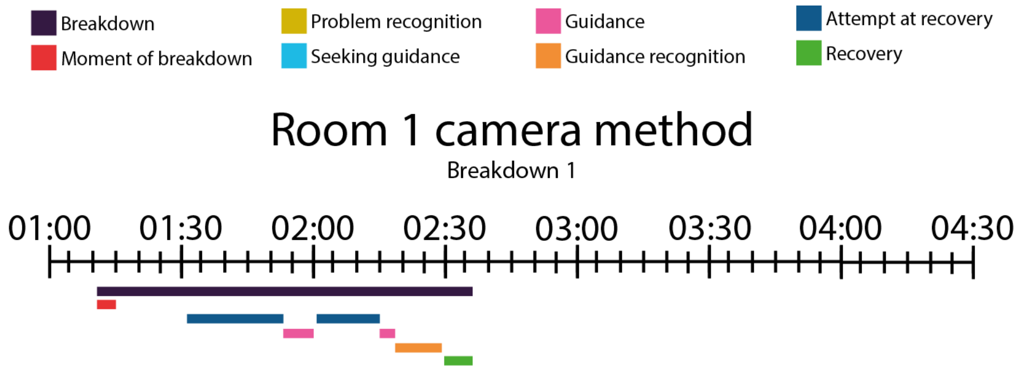

Figure 103 P5 B1 R1 camera

Breakdown 1 – initializing camera method: When starting the initialization of the camera, she followed the instructions. During this, the application recommended the user to aim at her feet and to move more slowly, to which she did, but the application never initialized. The participant was confused at this point, and I recommended her to cancel the initialization and restart, and if that would not work, she could attempt to go outside the room. She proceeded to attempt to scan the room more slowly this time, but still confused asking me if she should walk more around the room, to which I replied with that she could attempt to go outside to room 2 if that could work. This was acknowledged and done by the participant, resulting the camera method initializing. Once she saw the green pole appear and the application gave the visual feedback that it was ready to go, she acknowledged it.

Once she completed the initialization, I explained to her that a green pole had appeared, to which she had to place at each corner in the room, and I explained that if it did not automatically place the corner point, she could also tap the screen. She responded with standing at the entrance of the room placing the first corner point from a distance, and when placing the next corner, she moved closer. As she came closer to the second corner point, she pointed out that her first corner point was not at the position she first had put it. She decided to undo her steps at this point and started with replacing the first corner point.

When she had placed the first two corner points, she noticed once again that when she moved the former corner points had moved with her, making her confused. From this point out, she seemed a bit confused but placed the corner points at a rapid pace. Once she had connected all the corner points, she stated that “this doesn’t seem right”, but entering the setting ceiling height stage, she proceeded with following the instructions without any issues.

Figure 104 P5 B2 R1 camera

Breakdown 2 – restarting camera method: When the participant reached the finalize stage, it was clear that the shape of the room did not resemble the real-world example, and the participant was not pleased with the result. She stated that, she believed the issue is with her moving during the capturing, suggesting that she should stand at one position during the capturing. I therefore suggest that she could retry with the method, to which she agrees.

Attempt 2

During the second attempt, the participant was standing much closer to the first corner points, but during the whole capturing she was standing still at one position. This time, she did not experience issues with understanding how to use the interface. When reaching the corner with the shelves, the participant accepted the automatically placed corner when aiming straight towards the corner through the shelves. When reaching the ceiling height definition, she proceeded to set it immediately. When reaching the finalize stage, I forgot to mention to the participant that she could adjust the corner points, which she maybe would have done if she knew at that time.

Draw method

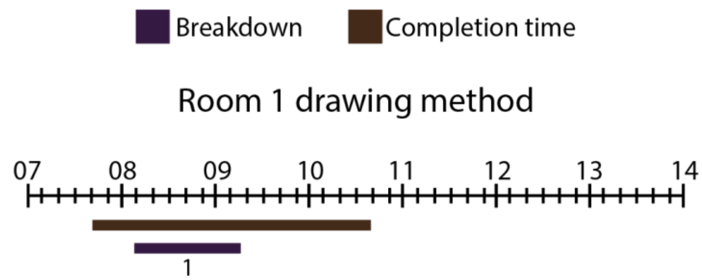

Figure 105 P5 R1 Breakdowns drawing

Before beginning with the draw method, I explained to the participant that each square of the grid equals 1 meter in real-life, and to create the shape of the room, she had to create corner points by tapping the screen where she wanted the corner point to be placed. By repeating this process, she would draw a wall. I also explained that she could zoom in and out of the interface by using her fingers.

Before placing the first corner point, the participant decided to use leg lengths to measure the length of the first wall, by walking beside it and counting the length. She then placed and adjusted the first corner point to the beginning of a square, making it seem that she understood how she could adjust and place the corners immediately.

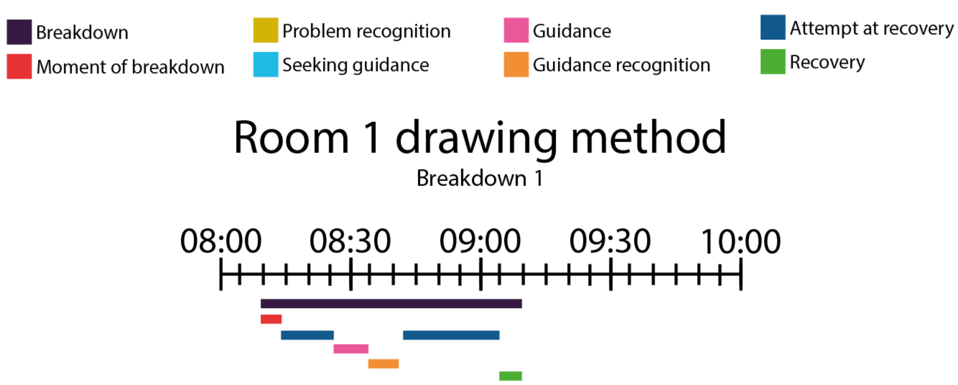

Figure 106 P5 B1 R1 drawing

Breakdown 1 – placing corners: However, once she reached her third corner point, she had to place it closely to the second one, and when she attempted to place the corner, the application would not register her input, and only targeted the selected corner point making her a bit confused. She tried by herself to register the third corner point, but I stepped in and suggested that she could zoom out and place a corner point further away, then readjust it. She struggled for a bit, but eventually were able to create a new corner point.

From this point, she struggled a bit to be efficient, but it seemed that she learned from breakdown 1, and she were able to place corner points, even though a lot of the time she placed the corner points by tapping multiple times. But she completed the drawing without any issues after breakdown 1 and recorded all the corner points. However, using her legs to measure the legs were not used after the one time in the beginning, suggesting that she was estimating by simply looking at it. Once she reached the finalize stage, I explained to her how she could now adjust each corner point or each wall, to adjust the measurements if she believes it is incorrect. I also enlighten her that she can now see the measurements next to each wall.

10.2.3 Room 2

Effectiveness

The participant used 8 minutes and 12 seconds to complete the task of room 2 with the drawing method, and 12 minutes with the camera method (see Table 42). Using 3 minutes and 48 faster compared to the camera method. Furthermore, the participant did not experience any breakdowns during either method. Additionally, to the drawing method using less time, it also scored a total of 18 points of maximum 20; while the camera method scored, 13 out of the 20 (see Table 43).

Room 2	Drawing	Camera
Time spent per method	8m 12s	12m
Time spent difference	3m 48s	
Number of breakdowns	0	0
Total time spent on breakdowns	0	0

Table 42 Person 5 room 2 completion overview

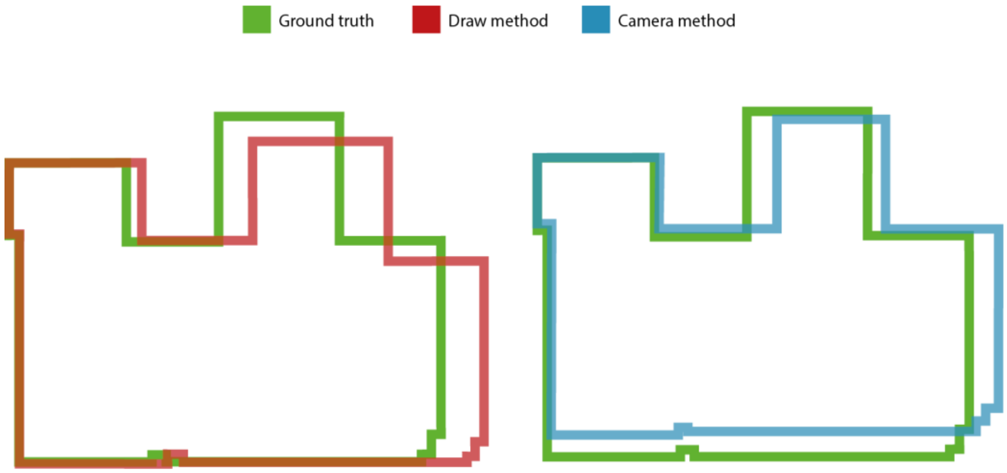

Figure 107 Person 5 Room 2 Output

Person 5 - Room 2

Wall	Wall	Ground truth (meters)	Ground truth (combined)	Drawing	Score	Camera	Score
Wall 1 (A+C+E)	Wall A	4,9m	5,63m	4,53m	1	4,5m	1
	Wall B	0,26m		0,23m	1	0,34m	0
	Wall C	0,53m		0,39m	0	0,34m	0
	Wall D	0,26m		0,21m	1	0,25m	1
	Wall E	0,2m		0,15m	1	0,27m	0
Wall 2 (F+H+J)	Wall F	6,53m	10,41m	7,27m	1	7,4m	1
	Wall G	0,18m		0,21m	1	0,1m	0
	Wall H	0,62m		0,67m	1	0,5m	0
	Wall I	0,18m		0,26m	0	0,2m	1
	Wall J	3,26m		3,68m	1	3,11m	1
Wall 3 (K+M)	Wall K	6,01m	7,66m	6,09m	1	5,6m	1
	Wall L	0,26m		0,27m	1	0,38m	0
	Wall M	1,65m		1,64m	1	1,5m	1
Wall N	Wall N	2,87m		3,27m	1	3m	1
Wall O	Wall O	2,12m		2,05m	1	1,89m	1
Wall P	Wall P	2,68m		3,19m	1	3,38m	0
Wall Q	Wall Q	3,32m		2,62m	1	2,9m	1
Wall R	Wall R	2,96m		3,35m	1	2,63m	1
Wall S	Wall S	3,32m		3,18m	1	2,9m	1
Wall T	Wall T	2,66m		2,54m	1	3m	1

Max Score	20	20
Sum score	18	13

Table 43 person 5 room 2 score

Learnability timeline

Camera method

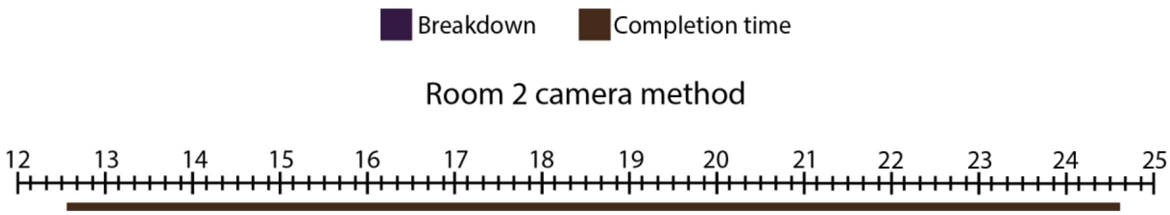

Figure 108 P5 R2 Breakdowns camera

When starting the camera method, she was a bit confused at first, asking me if she had to go around the room, before she realized that the camera had to initialize, to which it did instantly when she started to scan the room with the camera. Once it was initialized, she went straight to the first corner and recorded it without any problems. However, when she was recording the corner points from the bottom right corner (see Figure 107) and to the bottom left corner, she was standing from a distance, aiming at each corner point in front of objects, and not walking close to each corner point, like what she did during room 1. When she reached the corner with the cabinets (wall R), she made an estimation by placing the corner point behind it without knowing if it was the corner or not. During the rest of the capturing, she created all the corner point at a fast pace, with the same mind-set that each corner point should be created from a distance. She even stated right before she completed the connection of the corner points, which she had believed it would maybe not be as accurate as she thought. This time as well, she understood the ceiling height function without any help, and proceeded to set the height instantly.

When entering the finalize stage she realized that some of the walls were slightly skewed, and she doubted some of the measurements and decided that she wanted to adjust the corner points. From this point, the participant was able to adjust each corner point with ease, without many problems occurring with manoeuvring the interface. She understood well how to use the interface properly, and decided to adjust almost all the walls, by analysing each wall as she walked around the room. It was obvious during the analysis that she focused on capturing each wall accurately, but it is hard to tell how she estimates each length of the walls during this.

Draw method

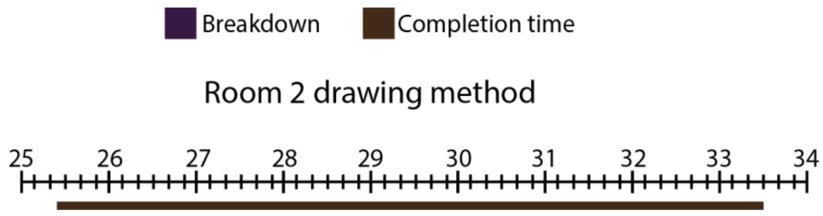

Figure 109 P5 R2 Breakdowns drawing

During the drawing method, it looked like the participant was quite comfortable with using the interface. She did not experience any breakdowns during this method either or were able to create the room with ease. However, even though she was efficient at using the zoom features and placing corner points efficiently throughout the test, she experienced some problems with registering new corner points when she was zoomed close to former corner points. This is something she could have fixed without any problems however, but rather something that seem to frustrate her. Other than that, the participant took her time to make sure each corner point was recorded, not much to add to this method, as it looked like the participant found this interface easy and quick to use.

Once she reached the finalize stage, she decided to adjust a few and was speaking to herself about each length of the wall during the readjustment, seeming like she was estimating a lot. Just before deciding to end, she stated that without any measuring tools, she did not believe that she could get any more accurate.

10.2.4 General thoughts from the participant

The participant stated during the interview that she found the camera method easier and quicker to use, as it was more user-friendly. She added that the camera method would be useful for a first draft of the room, as it was quicker to use compared to the drawing method, but she felt it was slightly more inaccurate. The participant explained the inaccuracy might have occurred as she felt the corner points were moving when she was moving throughout the room. She also added when using both methods, she had to adjust the measurements in hindsight anyways, so she believed it was easier to use the camera method, then readjust, even though she spent more time adjusting after the camera method compared to the drawing method. When asked if there was anything that made her frustrated when using the camera method, she stated that the corner points moving, as explained above was confusing.

The participant explained that during the drawing method, she wished that when placing a corner, she could lock it at its position, as she experienced sometimes that she would adjust former corners without meaning it. She added that this problem could cause her to adjust former corner points she was satisfied with, and she having to really focus on making sure it was recorded correctly, and not adjusted mistakenly. When asked if she felt this was a reoccurring issue, she stated that she felt it possibly became better once she got used to it but stating that 1 hour is maybe not enough to time to develop the required skills to use the interface optimally. In general, she stated that she found it a bit frustrating with the application to registering the taps sometimes as well. Furthermore, she stated that if she knew the measurements beforehand, she would have been able to create the room way faster, and she was certain that it would be more accurate than the camera method.

When asked which method she preferred, she answered that the camera method was the one she would choose as she felt she used less time with it, however, if she had known the measurements, she would have chosen the drawing method.

11 Comparison

In this comparison, I present data regarding breakdowns and score of each attempt with room one first, then room two following. In both room sections of this section of the appendix, I first present the data regarding the completion time and breakdowns, then secondly, present the data regarding the score, and lastly summarize the data. This is data such as time spent completing the tasks, number of breakdowns, breakdown durations, and present the scores achieved with each method. Lastly, I summarize the data for both methods and both rooms combined.

11.1 Room 1

In Figure 110, is a quick overview of the output each person made compared to the ground truth, with the green outline of the room is the ground truth, the red outline is the draw method output, and the blue outline being the camera method output. There are also a yellow outline highlighting the first attempt a user had if it were to be the case that a participant used more than one attempt. This colour is used for both methods.

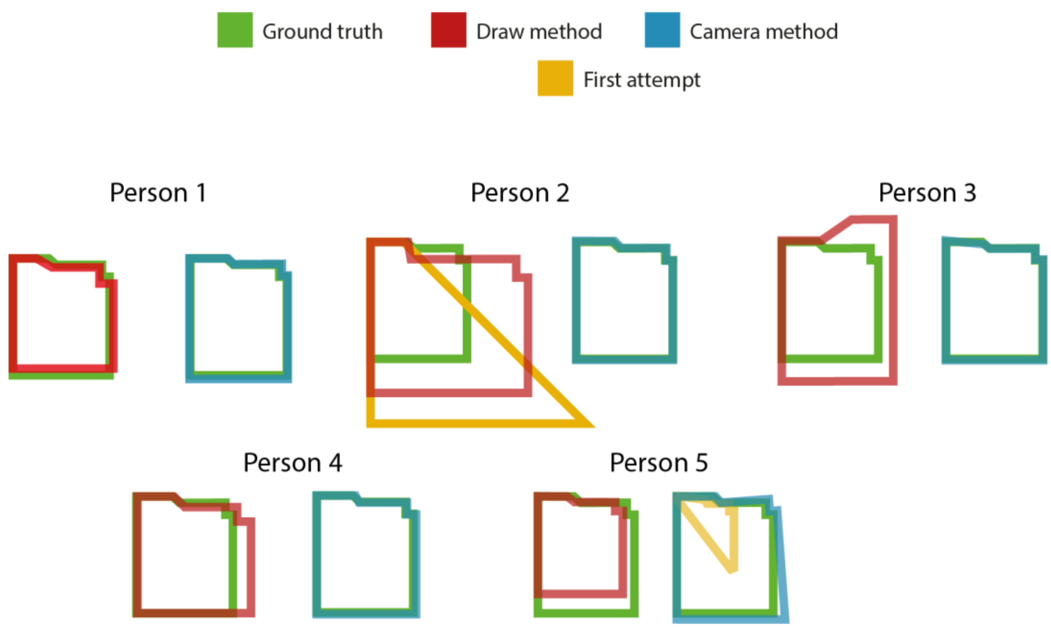

Figure 110 Room 1 output comparison

11.1.1 Completion time and breakdowns

When comparing the total completion time of each method, then a difference of 16 minutes and 44 seconds divide the two methods (see Table 45) with the drawing method being the one taking more time. However, this is probably due to the breakdown duration by person 1, which I will later address. Moreover, the total attempts per method is similar, as each person used only one attempt per method, except for person 2, who used two attempts on the drawing method, and person 5 used two attempts on the camera method.

In totality, the number of breakdowns for room 1 are quite similar, as the drawing method had 14 breakdowns (average number of breakdowns: 2.8) occurring while in the camera method, 13 (average number of breakdowns: 2.6) occurred. However, when comparing the total duration of the breakdowns in each method, then the drawing method used 18 minutes and 1 second longer than the camera method (see Table 45). When examining the persons one by one, an outlier is present, where person 1 used considerably longer on the breakdowns than the rest, which may have affected the totality (see Table 44). Furthermore, in Table 45, there are two rows explaining average breakdown duration. The first is the total average breakdown duration, meaning the average of all the persons combined breakdown duration per method, while the second is the average breakdown duration of all breakdowns in each method. The average breakdown duration for the drawing method is at 1 minute and 49 seconds, while the camera method had an average breakdown duration of 34 seconds, separating the two methods with 1 minute and 5 seconds.

Room 1	Person 1		Person 2		Person 3		Person 4		Person 5	
	Drawing	Camera	Drawing	Camera	Drawing	Camera	Drawing	Camera	Drawing	Camera
Attempts	1	1	2	1	1	1	1	1	1	2
Duration per method	15m 43s	3m 48s	8m 40s	3m 32s	3m 30s	3m 32s	4m 40s	2m 43s	2m 57s	5m 10s
# of breakdowns	6	5	2	2	2	1	3	3	1	2
Breakdowns duration	14m 7s	1m 34s	6m 27s	1m 20s	42s	1m 5s	3m 19s	1m 15s	58s	2m 18s

Table 44 Room 1 completion and breakdowns overview

Room 1	Drawing	Camera
Total attempts	6	6
Total time spent	35m 30s	18m 46s
Average time spent	7m 06s	3m 45s
Total number of breakdowns	14	13
Average number of breakdowns	2,8	2,6
Total time spent on breakdowns	25m 35s	7m 34s
Total average breakdown duration	5m 07s	1m 30s
Average breakdown duration	1m 49s	34s

Table 45 Room 1 completion and breakdowns summary

11.1.2 Score

Out of a maximum total score of 40 in room 1, meaning all persons combined, the drawing method scored a total 22 points, with an average score of 4.4. Meanwhile the camera method scored 36, with an average of 7.2 (see Table 47).

Room 1	Person 1		Person 2		Person 3		Person 4		Person 5	
	Drawing	Camera	Drawing	Camera	Drawing	Camera	Drawing	Camera	Drawing	Camera
Max total score	8	8	8	8	8	8	8	8	8	8
Total Score	4	7	2	8	3	7	6	6	7	8

Table 46 Room 1 complete score overview

	Room 1	
Method	Drawing	Camera
Max total score	40	40
Total Score	22	36
Max score (per person)	8	8
Average Score	4,4	7,2

Table 47 Room 1 complete score summary

11.1.3 Combined summary

In Table 48, the drawing method scored less out of the total score, with more total time spent and average time spent than the camera method. Additionally, the drawing method used a total of more time in total on breakdowns than the camera method, and more in average time spent per breakdown. However, the total number and average number of breakdowns are very similar.

	Room 1	
	Drawing	Camera
Max Total score combined	40	40
Total score combined	22	36
Total attempts	6	6
Total time spent	35m 30s	18m 46s
Average time spent	7m 06s	3m 45s
Total number of breakdowns	14	13
Average number of breakdowns	2,8	2,6
Total time spent on breakdowns	25m 35s	7m 34s
Total average breakdown duration	5m 07s	1m 30s
Average breakdown duration	1m 49s	34s

Table 48 Room 1 complete summary

11.2 Room 2

Like Figure 110, Figure 111 also highlight the individual outputs of each method compared to the ground truth, using the same colour code to the outline as previous. With green being the ground truth, red being the drawing method, while blue is the camera method, and as previously, the yellow outline is for the first attempt of the user used for both methods.

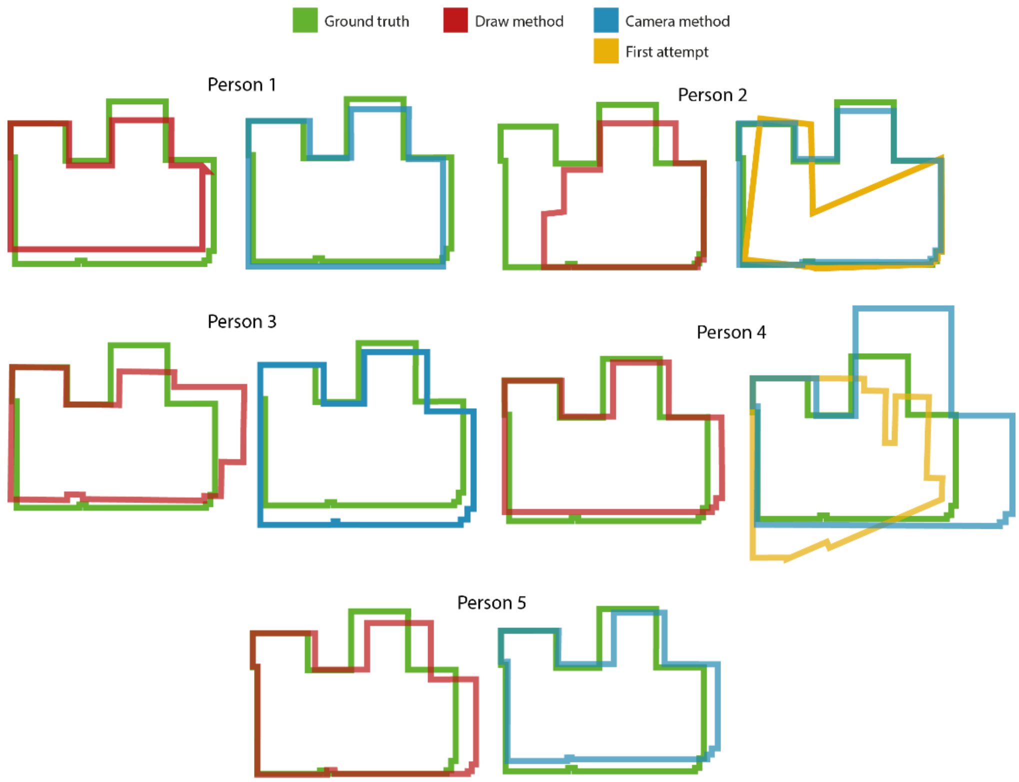

Figure 111 Room 2 output comparison

11.2.1 Completion time and breakdowns

In terms of completion time, both methods are very similar, using 47 minutes in total on both, with only 14 seconds longer with the camera method. The total average time spent on each method is also very similar, with the drawing method using 9 minutes and 27 seconds, while the camera method using 9 minutes and 30 seconds (see Table 50). Furthermore, the drawing method only required one attempt on all participants, while the camera method required two attempts on two participants.

The number of breakdowns is more divided in room two, than room one, as the drawing method had 15 breakdowns, while the camera method only experienced 8 breakdowns. However, the total time spent on all breakdowns combined per method is shorter on the drawing method than the camera method, separating them with 2 minutes and 43 seconds. Additionally, the average breakdown duration is at 59 seconds when using the drawing method, while 2 minutes and 24 seconds using the camera method.

Another thing to note is that two participants experienced zero breakdowns with the camera method, and one of these participants are person 5, which also did not experience any breakdowns with the drawing method as well (see Table 49).

Room 2	Person 1		Person 2		Person 3		Person 4		Person 5	
	Drawing	Camera	Drawing	Camera	Drawing	Camera	Drawing	Camera	Drawing	Camera
Attempts	1	1	1	2	1	1	1	2	1	1
Duration per method	7m 14s	5m	11m 43s	11m 25s	13m 16s	2m 42s	6m 52s	16m 24s	8m 12s	12m
# of breakdowns	2	1	6	4	4	0	3	3	0	0
Breakdowns duration	2m 28s	3m 18s	6m 13s	5m 27s	4m 54s	0	1m 18s	8m 52s	0	0

Table 49 Room 2 completion and breakdowns overview

Room 2	Drawing	Camera
Total attempts	5	7
Total time spent	47m 18s	47m 32s
Average time spent	9m 27s	9m 30s
Total number of breakdowns	15	8
Average number of breakdowns	3	1,6
Total time spent on breakdowns	14m 54s	17m 37s
Total average breakdown duration	2m 58s	3m 31s
Average breakdown duration	59s	2m 24s

Table 50 Room 2 completion and breakdowns summary

11.2.2 Score

In room 2, a total maximum score of 100 points (all participants combined) can be achieved with each method. Presented in Table 52, the drawing method scored a total of 53 points (average score per person: 10.6), and the camera method scored 52 points (average score per person: 10.4).

Room 2	Person 1		Person 2		Person 3		Person 4		Person 5	
	Drawing	Camera	Drawing	Camera	Drawing	Camera	Drawing	Camera	Drawing	Camera
Max total score	20	20	20	20	20	20	20	20	20	20
Total Score	8	8	5	13	8	11	14	7	18	13

Table 51 Room 2 complete score overview

	Room 2	
Method	Drawing	Camera
Max total score	100	100
Total Score	53	52
Max score (per person)	20	20
Average Score	10,6	10,4

Table 52 Room 2 complete score summary

11.2.3 Combined summary

As presented in Table 53, both methods scored similarly on room 2 in terms of points, and closely on time spent. As previously noted, differences in the breakdown occurrences, such as number of breakdowns and average time spent per breakdown are apparent. For instance, even though the drawing method had more breakdowns occurrences than the camera method, each breakdown was resolved quicker.

	Room 2	
	Drawing	Camera
Max Total score combined	100	100
Total score combined	53	52
Total attempts	5	7
Total time spent	47m 18s	47m 32s
Average time spent	9m 27s	9m 30s
Total number of breakdowns	15	8
Average number of breakdowns	3	1,6
Total time spent on breakdowns	14m 54s	17m 37s
Total average breakdown duration	2m 58s	3m 31s
Average breakdown duration	59s	2m 24s

Table 53 Room 2 complete summary

11.3 Summary

In both rooms combined, the drawing method scored a total of 75 points of a maximum 140, while the camera method scored 88 (see Table 54). The differences lie mainly in room 1, where the camera method scored 14 points more than the drawing method. However, the camera method took two more attempts total than the drawing method.

The total time spent per method are more even in room two compared to room one. For instance, in room one, the average time spent for the drawing method is 3 minutes and 21 seconds longer than the average time spent on completing the task with the camera method. However, this difference is only 3 seconds on room 2.

Lastly, the total number of breakdowns for the drawing method for room one and two are very similar, but with a 2 minute and 9 seconds decrease in average time spent recovering from a breakdown. Meanwhile, the camera method has a decrease in number of breakdowns, but a 2 minute and 1 second increase in average time spent recovering from a breakdown.

	Room 1		Room 2	
	Drawing	Camera	Drawing	Camera
Max Total score combined	40	40	100	100
Total score combined	22	36	53	52
Total attempts	6	6	5	7
Total time spent	35m 30s	18m 46s	47m 18s	47m 32s
Average time spent	7m 06s	3m 45s	9m 27s	9m 30s
Total number of breakdowns	14	13	15	8
Total time spent on breakdowns	25m 35s	7m 34s	14m 54s	17m 37s
Average breakdown duration	5m 07s	1m 30s	2m 58s	3m 31s

Table 54 Complete result summary