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KamerMaker:

A Novel Approach to the Reconstruction of Personal Indoor Spaces in Virtual Environments

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Master Thesis

24-11-2023

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Abstract

As Virtual Reality (VR) technology continues to evolve, it offers promising opportunities to transform treatment approaches in mental health and disability care, particularly for individuals with mild to borderline intellectual disability (MBID) suffering from substance use disorders. The aim of this research is the development of a novel system to personalize interventions by recreating the living spaces of individuals of the target group. The research explores various approaches to generating personalised immersive virtual environments (IVEs) mirroring the real-life living rooms of users. The resulting system is the KamerMaker system which makes use of an interactive touchscreen floorplan-based approach with a tunnelling-focussed approach where users can recreate their livings room by placing furniture and walls into the environment. The recreated virtual environments can then be experienced in VR. The evaluation test group consisted out of five participants that are all individuals with MBID. During the evaluation participants were asked to follow the presented instructions and were asked questions during a semi-structured interview. The resulting data was analysed by conducting a thematic analysis to identify the underlying theme's regarding the experiences of the participants. The findings revealed that the KamerMaker system was able to recreate livings rooms, but also resulted in a list of guidelines for future iterations of this novel approach. These results serve as a foundation for application related to this domain.

Acknowledgements

I want to start by expressing my gratitude to Randy and Simon, who have invested a substantial amount time and effort in guiding me during this period. They have shown an incredible level of professionalism, patience, and passion that has helped me through this journey that has been marked by personal highs and lows. Their consistent encouragement and mentorship during this period were instrumental in overcoming many obstacles thrown in the way.

Furthermore I would like to thank Joanneke for her valuable insights during the research phase of this thesis. I also would like to mention that thanks to you I've come to understand that criticism isn't something negative, but rather an opportunity for learning and growth.

I would also like to thank my parents and sister for sticking by my side and help me get through this period despite everything that life has thrown in our way. I would also like to thank my friends who always took their time to take part in discussions or helped me get back on the correct path.

I would like to end with the words that have marked the end of almost every Monday meeting that I've shared with Randy, Simon and Joanneke:

Alvast een fijn weekend gewenst!

Table of Contents

Acronyms

Acronym	Description	Page
MBID	Mild to Borderline Intellectual Disability	5
SUDs	Substance Use Disorders	5
AUD	Alcohol Use Disorder	5
DSM-5	Diagnostic and Statistical Manual of Mental Disorder (5th edition)	5
VR	Virtual Reality	5
IVE	Immersive Virtual Environment	6
VRT	Virtual Reality Therapy	6
VR-CET	Virtual Reality-Cue Exposure Therapy	6
VR-CBT	Virtual Reality-Cognitive Behaviour Therapy	6
PI	Place Illusion	6
Psi	Plausibility Illusion	6

Chapter 1: Introduction

In the domain of mental health and disability, the role of technology has been rapidly evolving, introducing new potential for treatment and support. One of these promising advancements is the use of Virtual Reality (VR), which has been applied in various contexts to better understand, diagnose, and treat a range of psychiatric disorders. However, the effectiveness of these technologies can depend significantly on the targeted demographic. This work focuses on a particularly vulnerable population, individuals with mild to borderline intellectual disability (MBID), and the potential application of VR in addressing a prevalent problem among this group, namely substance use disorders.

Among the substance use disorders prevalent in our society, alcohol use disorder (AUD) is particularly common. An estimated 23 million people suffer from AUD in the European Union, and in the United States, an estimated 32.6 million people are diagnosed with AUD (Sliedrecht et al., 2019). One group that's considered a risk group for developing substance use disorders (SUDs), such as AUD, are individuals with mild to borderline intellectual disability (MBID), as the consequences of their substance use are found to be more damaging (van Duijvenbode & VanDerNagel, 2019). With recent advances in Virtual Reality (VR) technology, improved tools for the assessment and intervention of psychiatric disorders, such as SUDs, have opened up (Ferreri et al., 2018, North & North, 2016).

One approach to VR therapy is VR exposure therapy (VRET) where patients are immersed into virtual environments and confronted with fear-inducing stimuli (when applied in the domain of anxiety disorders), or substance-related stimuli (when applied in the domain of SUDs) to disconnect conditioned psychological responses. Although VRET has shown promising results in the domain of anxiety disorders (Maples-Keller et al., 2017), mixed scientific evidence on the effectiveness of VRET has been found (Langener et al., 2021). Segawa et al., (2020) discuss the effectiveness of exposure therapy on inducing substance craving (i.e., the subjective, unwanted desire or urge to use a substance while attempting to abstain (Serre et al., 2015)), and highlights the potential of VR-cognitive behaviour therapy (VR-CBT), which focusses on learning coping strategies towards substance use impulses. Langener et al., (2021) additionally shows encouraging results of VR interventions, such as embodied learning, coping skills training, and aversive learning on disease severity and abstinence rates.

Virtual environments can control experiments and present stimuli dynamically within scenarios that accurately mimic real-world conditions (Parsons, 2015). These ecological valid scenarios often resemble naturalistic environments in which patients are immersed. However, these environments are predominantly manually developed and contain pre-defined scenarios resulting in limited personalisation capabilities.

Manually developing unique personalised IVEs is practically unfeasible due to the impractical amount of development time and resources required. This research will focus on developing a system that is capable of generating personalised context-focussed IVEs for individuals with MBID.

1.1 Background

The target group of this research are individuals that have MBID who additionally suffer from SUD, specifically AUD. Individuals diagnosed with MBID struggle with general mental abilities affecting their intellectual functioning (e.g., learning, problem solving, and judgement) and adaptive functioning, which is divided into three distinctive topics: (1) Conceptual, which relates to the understanding of language, reading, writing, and math. (2) Social, which concerns social abilities such as communication and empathy. (3) Practical, which involves the ability of looking after yourself (American Psychiatric Association, 2013). Individuals diagnosed with MBID are a risk group for developing SUDs and the consequences of their substance use are more critical (van Duijvenbode & VanDerNagel, 2019).

The Diagnostic and Statistical Manual of Mental Disorder (5th edition. DSM-5. American Psychiatric Association, 2013) defines AUD *"by a cluster of behavioural and physical symptoms, which can include withdrawal, tolerance, and craving"* (p.492). Craving, which can be defined as the subjective, unwanted desire or urge to use a substance while attempting to abstain (Serre et al., 2015), is considered one of the reasons why many people suffering from AUDs fail to exercise restraint even after treatment (Lee et al., 2007). Negative affect (e.g., anxiety, anger, sadness) and stress have been identified to impact of the levels of craving experienced by an individual (Ghiţă et al., 2019. van Lier et al., 2018), resulting in people neglecting other responsibilities such as going to work or be productive in general (American Psychiatric Association, 2013). Besides emotional states, environmental factors like the situation someone is in (e.g., being at a party or restaurant), the presence of other people, and the type of alcoholic beverage also impact feelings of craving in people diagnosed with AUD (Ghiţă et al., 2019). Based on findings of the WHO World Mental Health Surveys a worldwide lifetime prevalence of AUD is found to be 8.6% and ranges from 0.7% in Iraq to 22.7% in Australia. The Netherlands, the country in which this research was conducted, has a lifetime prevalence of 8.9%, indicating that misuse of alcohol is moderately common in society (Glantz et al., 2020).

There are a variety of approaches to the assessment and treatment of mental health disorders like AUD, such as cue-exposure therapy and cognitive behaviour therapy. With recent advances in Virtual Reality (VR) technology improved tools for the assessment and treatment of psychological disorders have opened up (North & North, 2016). There already have been multiple implementation of VR in studies that focus on substance use disorders such as nicotine use disorder (Culbertson et al., 2012. Pericot-Valverde et al., 2019. Traylor et al., 2011), alcohol use disorder

(Bordnick et al., 2008. Lee et al., 2007), and methamphetamine use disorder (Seow et al., 2020). These studies developed Immersive Virtual Environments (IVEs) containing settings that resemble realistic contexts to be used in Virtual Reality Therapy (VRT) approaches, such as VR-CET and VR-CBT. By being able to immerse patients into these realistic context's scientists may be able to achieve higher levels of ecological validity of their experiment, whilst keeping control of the environment. Using VR, in the context of improving the mental health of people, therefore offers new opportunities (Bouchard & Rizzo, 2019), as the it *"may result in a participant within a virtual reality realistically responding to events and situations"* (Slater, 2009, p.3556).

Slater, (2009) discussed two components which contribute to inducing these realistic behavioural responses in IVEs. Place illusion (PI), which is often described as the sense of "being there" (Witmer & Singer, 1998) and plausibility illusion (Psi), which concerns the illusion that what is happening in the IVE is experienced as an actual situation even though the user is aware that it is not actually happening. PI, also often referred to as 'presence' or 'spatial presence', has been discussed to be influenced by four main factors: Engagement, personal characteristics, interaction fidelity, and display fidelity (Souza et al., 2021).

The focus on an individual's unique history and personal traits during Virtual Reality Therapy has been discussed as being an important factor in improving the effectiveness of treatments for SUDs. Kritikos et al., (2021) emphasized that when the nature, the character and the behavioural traits of an individual patient are not considered, efficacy and duration of a treatment are significantly affected. Most VR intervention approaches for individuals with SUD and MBID could benefit from personalised ecological valid IVEs, which is the focus of this research.

1.2 Research Problem

When examining existing VR intervention approaches it is noticeable that these studies predominantly use manually developed IVEs containing pre-defined scenarios. Understandably, as manually developing personalised IVEs for each patient is practically unfeasible due to the impractical amounts of development time and resources needed. This research is focussed on developing a system that makes it possible for individuals with MBID and AUD to easily recreate context-focused environments into immersable IVEs.

1.3 Research Questions

Based on the problem statement discussed in the previous section, the following main research question has been formulated:

> RQ: *How to reconstruct personalised indoor contextual immersive virtual environments for addictive disorders treatments for individuals with mild to borderline intellectual disability?*

To be able to answer this main research question, four sub-research questions are formulated. RQ1 aims to identify specific contexts and context-related elements that are generally capable in eliciting alcohol-related cue reactivity in individuals with AUD and MBID. The term 'context' relates to the location or situation of the environment (e.g., someone's living room or a party in at a friend's house). The term 'context-related elements' relates to individual aspects of the context (e.g., presence of other people, the location of the television in the living room). RQ2 is focussed on identifying a suitable process for procedurally generating IVEs using personalised contextual information regarding AUD. This RQ has been divided into two additional research questions, which try to find out how architectural interiors/exteriors can be generated in general and how personalised contextual information (i.e., geometric and semantic information as described by Silveira et al., (2016)) can be acquired from individuals with MBID. RQ3 focusses on the evaluation of the system, of both the information extraction through the use of a tablet section, and the IVE section. Finally, RQ4 focusses on identifying how users experience this system in terms of user experience and usability.

The research questions have been formulated as follows:

> RQ1: *Which contexts and context-related elements elicit alcohol-related cue reactivity in individuals with AUD and MBID?*
>
> RQ2: *How can indoor spaces be reconstructed using personalised contextual information acquired from individuals with MBID?*
>
> > RQ2.1: *How can indoor spaces be reconstructed in 3D?*
> >
> > RQ2.2: *How can personalised geometric and semantic information be obtained from individuals with MBID?*
>
> RQ3: *How do users of the target group experience the geometric and semantic information extraction?*
>
> RQ4: *How do users of the target group experience the reconstructed personalised immersive virtual environment?*

Chapter 2. Alcohol Use Disorder and Related Contexts

This section is focussed on gaining a better understanding on the topic of AUD and provide key information on the topic. Additionally, this section is focussed on finding an answer to RQ1: *Which contexts and context-related elements elicit alcohol-related cue reactivity in individuals with AUD and MBID?*

2.1 Background on Alcohol Use Disorder

AUD is a prevalent disorder in society as it is estimated that in the European Union 23 million people suffer from the disorder, and an estimated 32.6 million people are diagnosed with AUD in the United States (Sliedrecht et al., 2019). The Diagnostic and Statistical Manual of Mental Disorder (5th edition, DSM-5, American Psychiatric Association, 2013) defines AUD *"by a cluster of behavioural and physical symptoms, which can include withdrawal, tolerance, and craving"* (p.492). The DSM-5 presents 11 criteria for the diagnosis of AUD including the sensation of alcohol craving, which is often defined as *"the subjective, unwanted desire or urge to use a substance while attempting to abstain"* (Serre et al., 2015, p.2), and is often used as a research outcome measurement (see Appendix A for the 11 criteria for AUD). A distinction between mild, moderate, and severe AUD is made based on the number of criteria that are met. Individuals are diagnosed with mild AUD when two to three criteria of the DSM-5 are present, moderate AUD is diagnosed when four to five criteria are present, and severe AUD is diagnosed when six or more criteria are identified (American Psychiatric Association, 2013).

Although some people recover from AUD without the help from professionals or official treatments (Sliedrecht et al., 2019), others experience AUD as a *"chronic, recurring condition involving multiple cycles of treatment, abstinence, and relapse"* (McKay & Hiller-Sturmhofel, 2011, p.1). Although a general consensus on the definition of relapse is missing, Sliedrecht et al., (2019) defined it as *"an absence of abstinence"* (p.99). Van Duijvenbode & VanDerNagel, (2019) discusses that substance use disorders (SUD), of which AUD is one, are multidimensional issues based on the complex interplay of three factors: biological factors (e.g., genetics, physiological effects of substances), psychological factors (e.g., personality traits, comorbid psychiatric disorders), and social factors (e.g., socioeconomic status, peer pressure, SU by important others). These factors are also highlighted in the research conducted by Sliedrecht et al., (2019), but additionally included spiritual determinants (see p.102-105 for an in-depth overview of determinants of alcohol relapse/remission).

As AUD is a complex disorder with many different determinants for possible relapse, *"treatment needs to consider the many different aspects that contribute to the client's drinking patterns"* (Campbell et al., 2018, p.1759). Various approaches to treating these different aspects have been developed, such as pharmacotherapy (i.e., treatment through medication) for craving control and increased motivation to stay sober, peer support to inform the clients' social environments with information to create an environment that facilitates abstinence, and Cognitive Behavioural Therapy (CBT) to help the client alter its dysfunctional behaviour and cognitive patterns (Campbell et al., 2018). CBT is a psychological treatment approach of which its efficacy has been indicated on treating bulimia, anxiety disorder, depression and stress (Hofmann et al., 2012), but also for alcohol and substance use disorders (McHugh et al., 2010). CBT in the context of SUDs is a combination of strategies from *cognitive therapy*, which focusses on understanding the patient's thoughts during exposure to substance stimuli, and *behavioural therapy*, which focusses on the patient's actions resulting from exposure to substance stimuli. Patients are taught how to identify and avoid substance-related triggers and are trained in developing coping mechanisms towards thoughts and feelings resulting from substance triggers.

2.2 Alcohol-related Cue-Reactivity

Exposing individuals to ecological valid AUD-related situations/stimuli in interventions intents on eliciting cue-reactivity. Cue-reactivity, in the context of AUD, represents conditioned responses to alcohol-related stimuli, such as subjective craving and psychophysiological responses (e.g., galvanic skin responses, heart rate and body temperature, Bordnick et al., 2008). CBT-based interventions focus on training individuals with AUD to recognize certain thought patterns they engage in before consuming alcoholic beverages, and attempt to identify relevant alcohol-related environmental factors. Once these factors have been established, cue-reactivity is induced to train patients to cope with craving temptation (Keijsers et al., 2021).

Identifying these relevant alcohol-related environmental stimuli is important in this research. Cue-reactivity can be elicited through exposure to various stimuli, Conklin et al., (2008) discussed three different types of stimuli in the field of substance use:

(1) *Proximal stimuli*, which are universal across substance use such as paraphernalia directly linked to a specific substance. These can be visual stimuli, such as lit cigarettes, lighters, and ashtrays in the case of nicotine-dependence, or bottles of alcohol in the case of AUD, as well as olfactory- (i.e., sense of smell), auditory-, or tactile stimuli.

(2) *Contextual/Distal stimuli* are stimuli that are not directly linked to substance use, but have been frequently present during when using a substance. They often relate to environments or contexts in which substance use occurs, such as a bar or a party in the case of AUD and nicotine dependence. These contextual stimuli may be further subdivided into environments with or without social interactions (Traylor et al., 2011).

(3) *Complex stimuli* are the combination of proximal and contextual stimuli, which represent a more complete picture of a real-world environment containing substance paraphernalia.

Conklin et al., (2008) found that similarly to proximal stimuli, contextual/distal stimuli can independently evoke cue-reactivity. Fatseas et al., (2015) discussed the distinction between substance-related stimuli and person-specific stimuli. It was found that although substance-related stimuli do elicit feeling of craving in individuals, person-specific stimuli have a more robust impact of craving which last for a longer time period. For example, individuals diagnosed with AUD may experience greater feelings of subjective craving when exposed to a bottle of alcohol of their preference or when positioned in a known contextual environment (e.g., their go-to pub). This research is focussed on reconstructing personalised contextual 3D environments; therefore, the section aims to identify prevalent alcohol-related contexts which induce cue-reactivity.

2.3 Identification of Prevalent Alcohol-related Contextual Stimuli.

A study conducted by Ghiţă et al., (2019) aimed to identify alcohol craving-related triggers to benefit VR-CET for patients with AUD who are resistant to classical treatment. As craving *"is a core mechanism in the acquisition, maintenance, and precipitation of relapse in AUD"* (p.1) it was selected to measure cue-reactivity. They developed a questionnaire with six variables to assess alcohol-craving levels when exposed to alcohol-related stimuli. One of these variables is the *situation/location* where individuals are exposed to stimuli. They found that being at a party, in a restaurant, in a bar, in a pub, and in a house, either your own or someone else's, resulted in the higher alcohol craving, respectively. Being in the workplace, the bedroom, a supermarket, and parks was found to elicit lower levels of craving. Other identified variables are *Presence of others*, of which drinking alone or drinking with one or with two or more friends was reported to elicit significant craving. Interestingly, Cho et al., (2008) focused on the role of social pressure and found that significantly higher alcohol craving was induced when avatars were included; *Time of the day*, with increased craving in the afternoon and night; *Day of the week*, with increased craving in the weekend; *Type of alcoholic beverage*, where the most common craving-related beverages were beer, wine, and whiskey; *Mood*, where negative emotions such as anxiousness, tenseness, sadness, being stressed, and being frustrated contribute to significantly increased levels of craving.

Another qualitative research conducted by van Ast, (2021) focussed on researching the possibilities and benefits of VR for individuals with MBID (IQ varied between 50 and 85) who suffer from AUD who will be discharged from a rehab centre in the near future. During this research ten interviews were conducted with the target population, of which one section of the interviews concerned situations that elicit alcohol craving. The most commonly mentioned situations are the patient's living room, supermarket, “atmospheric” surrounding, and a specific route outside on the streets. All identified triggers were roughly divided into four separate groups:

(1) Direct confrontation with alcohol through visual, olfactory, auditory, or tactile stimuli (i.e., proximal stimuli as discussed by Conklin et al., (2008)).
(2) Social pressure, in the form of being invited to come over for a drink (i.e., impact of social pressure as discussed by (Traylor et al., 2011)).
(3) Contextual mood, where specific positive/negative situations cause specific emotions which result in alcohol craving.
(4) Observations which have indirect relations with alcohol use. Examples mentioned are beautiful weather, watching television, having money in your wallet, coming in contact of a specific individual.

2.4 Discussion

To find an answer on RQ1, the topic of AUD was explored.

Understanding cue-reactivity: Understand cue-reactivity is a crucial element of therapies for AUD, such as Cognitive Behavioural Therapy (CBT). These conditioned responses to alcohol-related stimuli include subjective cravings and physiological responses like galvanic skin response, heart rate, and body temperature changes (Bordnick et al., 2008). By simulating the triggers that cause these reactions, VR can provide customized and more effective interventions for individuals dealing with AUD.

AUD-related contexts: Understanding the specific contexts that are commonly associated with relapse and increased cravings is key for enhancing cue-reactivity. Studies have identified a number of contexts, like parties, restaurants, bars, pubs, and houses (Ghiţă et al., 2019), a supermarket and “atmospheric” surrounding (van Ast, 2021) To choose the most suitable context for our system is difficult as it very subjective and depends on the history of the users. However, further investigation into the specifics of MBID could provide a better base as it could lead to more specific contexts. The choice of context should also consider the cultural background of the users. Ghiţă and colleagues found lower levels of alcohol craving in supermarkets and living rooms, which contradicts the findings of van Ast who found these environments highly likely to induce cravings. The discrepancy may be due to cultural differences, as Ghiţă et al.'s study was conducted in Spain, while van Ast's research took place in the Netherlands.

Chapter 3. Mild to Borderline Intellectual Disability

As mentioned, the target group of this research are individuals with a dual diagnosis of mild to borderline Intellectual Disability (MBID) and alcohol use disorder (AUD). In the previous section, characteristics of individuals with AUD in general were highlighted. This section will focus on individuals with dual diagnosis of AUD and MBID. First, background information will be provided concerning MBID in general, followed by key characteristics of this type of dual diagnosis. Next, barriers to the use of technology for people with MBID is discussed, followed by information on how products can be designed for people with MBID.

3.1 Background on MBID.

The Diagnostic and Statistical Manual of the American Psychiatric Association, Fifth Edition (DSM-5, American Psychiatric Association, 2013) defines an intellectual disability as a *"a disorder with onset during the developmental period that includes both intellectual and adaptive functioning deficits in conceptual, social, and practical domains."* (p. 33). Intellectual functions refers to mental abilities, such as *"reasoning, problem solving, planning, abstract thinking, academic learning, judgement, and learning from experience"* (American Psychiatric Association, 2013, p.33), and is measured by standardised IQ tests, such as the Wechsler Adult Intelligence Scale Fourth Edition (WAIS-IV, Wechsler, 2008). Adaptive functioning refers to specific skills that are needed to function in a day-to-day life. Deficits in this type of functioning result in *"failure to meet developmental and sociocultural standards for personal independence and social responsibility"* (American Psychiatric Association, 2013, p.33). Adaptive functioning is divided into three distinctive domains:

(1) *Conceptual*, which relates to the understanding of language, reading, writing, and math, the way people speak and learn a language, and the way they understand their surroundings.
(2) *Social*, involves the awareness of others' thoughts, feelings, and experiences, which concerns social abilities such as communication and empathy, but also the ability to understand and follow social rules.
(3) *Practical*, which involves the ability of looking after yourself and managing responsibilities of one's daily life, as well as the ability to manage one's behaviour, and task organization.

Intellectual disability has been divided into separate severity levels (i.e., mild, moderate, severe, profound), and their definition is founded on the adaptive functioning of individuals and not their IQ scores, as adaptive functioning is the determinant for the level of support required (American Psychiatric Association, 2013). IQ scores, however, are used for categorization of intellectual functioning. Mild intellectual disability (MID) is characterized by significantly impaired intellectual and adaptive functioning, generally defined as having an IQ between 50 and 70. Though not defined as a severity level of intellectual disability, borderline intellectual functionality (BIF) refers to a person having below average cognitive abilities, and is generally defined as having an IQ between 70 and 85. The target group of this research contains individuals with MID and BIF, or MBID (i.e., IQ between 50 and 85), as *"it has become clear that individuals with MBID often experience more severe consequences of* [substance use] *and are a risk group for developing SUD"* (van Duijvenbode & VanDerNagel, 2019, p.2).

3.2 Barriers to Technology Use by Individuals with MBID.

Wehmeyer et al., (2004) discussed two categories of barriers that are found to be particularly important, which could be defined as internal and external barriers (Nystedt, 2019). Internal barriers refer to limitations of technology use due to the characteristics of individuals with MBID. External barriers, on the other hand, relate to external factors that obstruct the accessibility and user experience of the technology, such as the lack of universal design features that take intellectual disability into account. Both categories should be considered when designing and developing technology meant for people with MBID.

3.2.1 Internal Barriers to Technology Use.

Internal barriers relate to the aforementioned characteristics in cognitive functioning of people with MBID. In his book, Carroll, (1993) reviewed and reanalysed the existing literature on individual differences in cognitive abilities of people. This section will describe the five domains of cognitive abilities that were identified by Carroll and additionally includes Wehmeyer et al., (2004) findings of his comprehensive examinations on the impact of these cognitive abilities on technology use by students and adults with intellectual disabilities.

Language, communication, and auditory reception domain.

This domain refers to the abilities that are associated with the conceptual domain of adaptive functioning and relates to the competences of an individual's vocabulary, grammar, reading comprehension, reading speed, and oral production ability.

Often used input types in technology, such as voice commands (e.g., Siri in Apple products, Alexa in Amazon products, and Google Assistant) and typing commands (e.g., keyboards and touchscreens), can form substantial barriers for people with MBID as they are limited by their reading, linguistic and verbal comprehension. Instructions and communicative elements in technology often use written texts with ranging complexity, which acts as an obstacle for their accessibility to this group. Recent years have seen improvements in this field as new abstract definitions were introduced for common terms; however, these terms can be challenging to understand for people with intellectual disabilities because of their metaphoric natures (e.g., menu, file, window, mouse, and tools). Terminology related to more literal and concrete representations of the world could diminish this barrier.

Reasoning, working memory, and cognitive speed domain.

This domain refers to the ability to process information. Cognitive speed refers to the ability to rapidly process information accurately, whereas working memory *"is a basic cognitive mechanism (or set of mechanisms) that is responsible for keeping track of multiple task-related goals and subgoals, or integrating multiple sources of information."* (Miyake & Shah, 1997, p.1). Carroll, (1993) discussed three main independent dimensions of ability in reasoning:

- *Sequential reasoning*, the ability to *"engage in one or more steps of reasoning to reach a conclusion that properly and logically follows from the given premises"* (p.245).
- *Induction*, the ability to derive a general principle from observations.
- *Quantitative reasoning*, the ability to reason with mathematical relations in order to draw correct conclusions.

Current computer programs often present the user a plethora of interactive options simultaneously, which forms a barrier for people with MBID. Their deficit in reasoning abilities, and idea production hampers the use of systems providing this option. Limiting choice options in systems is therefore beneficial to implement. Necessity of cognitive speed of users could influence the effectiveness of specific systems, as this dependency will obstruct the accessibility for people with MBID (e.g., a timer-based camera).

Memory and learning domain.

This domain refers to the ability to retain or forget a memory of the outcomes of learning processes. Five factors of memory abilities are discussed:

- *Memory span*, the ability indicated by the amount of material that can be immediately recalled after being exposed to it in the correct order.
- *Associative Memory*, the ability to learn and recall relationships between unrelated materials.
- *Free Recall Memory,* the ability to recall a set of materials after exposure (non-immediate) in any order.
- *Meaningful Memory*, the ability to recall more material when it has personal meaning to them.
- *Visual Memory*, the ability to form mental representations of visual materials.

Furthermore, a form of memory is recognition memory, which *"to the ability to identify as familiar a stimulus or a situation that has been encountered previously."* (Moreno-Castilla et al., 2018, p.8). People with MBID also find it difficult to generalize lessons learned from one situation to another, resulting in problem solving issues when problems arise during technology interaction. Limitations in memory also hinders the use of technology as memory is often needed when operating these systems (e.g., memorizing sequences of commands).

Visual perception abilities domain.
This domain refers to abilities in *"searching the visual field, apprehending the forms, shapes, and positions of objects as visually perceived,* [and] *forming mental representations"* (Carroll, 1993, p.304). It concerns the ability to quickly manipulate visual patterns, or apprehend and identify visual patterns when the patterns are disguised in some way. Additionally, abilities to follow an indicated route or path, being capable of creating mental representations of visual patterns which can be used in spatial problems, and accurately estimate visual lengths or distances without measuring instruments are also a part of this domain.

Graphical user interfaces often use pointing devices, such as a mouses, resulting in the importance of being able to scan, locate and act upon information provided by the system. Maintaining attention to relevant stimuli when viewing complex displays can be overwhelming for people with MBID. The usage of a mouse can be replaced by touchscreens, as *"touchscreen devices can open up a world of new possibilities for people with [MBID]–changing the way they see, hear and interact with the world"* (Kversøy et al., 2020, p.8).

Knowledge and achievement abilities domain.
This domain refers to general school achievements and knowledge in topics, such as mathematics and science, and technical and mechanical knowledge. Programs on systems that allow people to obtain new knowledge on various topics is often not age-appropriate for people with MBID.

3.2.2 External Barriers for Technology Use.

As mentioned, external barriers that people with MBID face when interacting with technology relate to external factors that obstruct the accessibility of the technology. A major key in the inaccessibility of technology for people with MBID is that *"most hardware and software has been, and continues to be, designed by and for people who are not disabled.",* with the reason that *"design for disability is not cost effective."* (Glinert & York, 2008, p.2). However, through the years various proactive design approaches have been proposed where the primary focus is the usability and accessibility of technology for everyone.

Universal Design Approach (or Design for All) is such a proactive design approach. The Centre for Universal Design at North Carolina State University defined Universal Design as *"the design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design"* (Mace et al., 1997). This approach contains seven principles which can be found in Appendix B: *'Universal Design Principles'*. An example of a principle included into this approach is the principle of 'Tolerance for Error', meaning that designs minimizes the possibility of accidental or unintended actions. These principles, although relevant, are too broad and do not focus specifically on the characteristics of the target group.

A work in progress document by Seeman-Horwitz et al., (2021) provides assistance on making usable (web)content for individuals with cognitive and learning disabilities, including intellectual disabilities. Nine key topics have been identified and each topic is supported by information related to the users' needs, design patterns that provide practical guidance to improve the accessibility of designs and the design process, and guidance in user testing each topic. Appendix C: *'Making Content Usable for People with Cognitive and Learning Disabilities'* contains a short description of each topic included into the document.

With regards to developing increasing accessible and usable mobile/touchscreen applications for people with MBID, Dekelver et al., (2015) discussed a grouped set of design recommendations which could support developers in their design process. They are divided into three topics: navigation and graphic design, requirements to the text, and personalisation. These recommendations can be found in Appendix D: *'Grouped Recommendations for Developers of Mobile Applications Interfaces for People with MBID'*.

3.3 Discussion

To find an answer on RQ2, the topic of MBID was explored.

- *Internal Barriers for Technology Use*: Internal barriers are tied to individual limitations and are grouped into five domains according to Carroll, (1993): language, communication, and auditory reception; reasoning, working memory, and cognitive speed; memory and learning; visual perception abilities; and knowledge and achievement abilities. Wehmeyer et al., (2004) presented these barriers in the light of technology use. When designing an application for this target group it will be important to identify how these domains can be properly addressed so that we can limit the presence of these barriers. It's important to note that both Carroll's and Wehmeyer's research, conducted three and two decades ago resp., happened in a time where the technological landscape was extremely different than today. While the fundamentals remain relevant, the evolution of technology could result in considerations that their research doesn't cover. Therefore, while using Carroll's and Wehmeyer's findings as a base, it's essential to recognize this limitation.

- *External Barriers for Technology Use*: Three recommendation approaches for developing applications for people with an intellectual disability were discussed in order to acquire a better perception on potential external barriers. The Universal Design Approach contains broad principles in order to address the needs of all possible user backgrounds (Mace et al., 1997), the work-in-progress document by Seeman-Horwitz et al., (2021) provides assistance when developing web content for individuals with cognitive and learning disabilities, and Dekelver et al., (2015) discussed a grouped set of design recommendations which could support developers in their design process of mobile applications for people with MBID. Across these design approaches, common themes emerge such as error prevention mechanisms, the use of clear labels and instructions, and the need for personalization.

- *Personalisation*: From the perspective of interaction technology, internal and external barriers are not as detached as these categories are not so much separate entities but rather interconnected aspects that influence each other. For instance, individuals' internal conditions, such as their cognitive speed or auditory reception, directly affect how they interact with specific technological interactions. On the other hand, these external factors, like the user interface of an application or the technological features of a device, impact how the individual navigates, perceives and interacts with the technology, influencing their internal conditions. This brings up the importance of personalisation in technology design, especially when catering to individuals with MBID. Since the internal barriers and limitations vary greatly from person to person, the design of the technology should accordingly be flexible and adaptable. By focussing on personalisation, we could meet the individual's unique needs and preferences and

Personalisation could be implemented in various forms, such as adjustable text size for those with visual perception abilities, a simplified interface for those struggling with cognitive speed, or an audio guidance feature for individuals with stronger auditory reception. How personalised aspects are implemented should also be considered, as indicating these preferences should not be an exhaustive task, but rather seamlessly realized to reduce cognitive load.

Chapter 4. 3D Indoor Model Reconstruction Methods

In order to find an answer to RQ2: '*How can indoor spaces be reconstructed using personalised contextual information acquired from individuals with MBID?*', a related work analysis will be conducted to identify various approaches to reconstructing specific indoor spaces into 3D environments. With the goal of recreating personalised contextual immersive virtual environments in mind, it is key to extract the personal styles and designs of such indoor spaces. In a study conducted by Silveira et al., (2016) a distinction was made between two architectural information input types:

- *Geometric Information,* which relates to the three-dimensional geometry of the indoor space containing a list with all the positional and dimensional data of walls, doors, windows, and furniture.
- *Semantic information*, which relates to the styles and designs of the indoor space. In this research this includes the textures and characteristics of the interior surfaces of the space (e.g., an oak floor in a specific pattern, red brick walls), and the textures and characteristics of the furniture (e.g., a red coach, a 36" flatscreen television).

The combination of both architectural information types will provide the framework for the recreation of a 3D reconstruction of a specific indoor space. In their study, Silveira et al., (2016) used a procedural generation process (i.e., generating 'something' algorithmically, rather than performing manual design and development) to transform the provided information into a generated 3D model. This section aims to highlight various other approaches capable of extracting indoor architectural information and bring to light the processes used to transform architectural information into a 3D reconstruction. Three grouped approaches to obtaining the desired information are discussed in this section:

(1) *Point cloud-based reconstruction,* which is related to creating a 3D point cloud of indoor environments through 3D scanning and LiDAR scanning.
(2) *Photographic-based reconstruction*, which relates to using single-view estimation and multi-view estimation.
(3) *2D Floorplan Reconstruction*, which related to transforming existing, randomly generated, or self-drawn 2D floorplans into usable architectural information.

The goal of this section is to explore the existing mechanisms of these approaches to get a better understanding on how these methods operate and find an answer to RQ2.1: *How can indoor spaces be reconstructed as a 3D model?*

4.1 Point Cloud-based Reconstruction

A point cloud is a set of data points in space representing a 3D object, where each point in the cloud has a set of Cartesian coordinates (x, y, z) to indicate its position. These clouds can be obtained through scanning methods, and be transformed into 3D environments. Four categories of point cloud 3D reconstruction methods have been identified: planar-based reconstruction, volumetric-based reconstruction, mesh-based reconstruction, and indoor scene interpretation with semantic labelling. To highlight one method: planar-based reconstruction focuses on identifying and creating polygons that make up an indoor space by detecting primitive planes in a point cloud using methods such as region growing, direct segmentation (Peternell & Steiner, 2004), and the efficient RANSAC algorithm (Schnabel et al., 2007). An example of a planar-based reconstruction framework is PolyFit by Nan & Wonka, (2017), of which its process can be seen in *Figure 1*. Of a point cloud model (a) points lying in a matching plane are highlighted to identify planar segments (b), followed by clipping the supported planes with each other (c). Pairwise intersections are calculated to produce candidate faces of a model (d) after which an optimal subset of candidate faces are selected to produce a watertight polygonal model (e). To acquire a better understanding of the other reconstruction methods I'll redirect you to the dissertation of Nikoohemat et al., (2020, p.19-37) who provides an extensive and clear explanation.

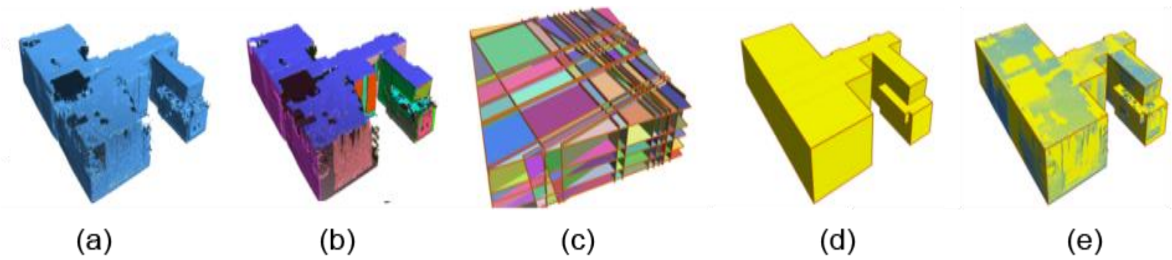

Figure 1: Planar-based reconstructing of lightweight polygonal surfaces from point clouds of Nan & Wonka, (2017).

4.1.1 High-end 3D Scanners and Indoor Mobile Mapping Systems.

High-end 3D scanners make use of Simultaneous Localization and Mapping (SLAM) technology where data of environments is collected and transformed into a 3D point cloud whilst tracking the scanner position in the space. Utilizing this technology is a common strategy for Indoor Mobile Mapping Systems (Chen et al., 2018). High-end indoor mapping systems, however, are relatively expensive[1] (e.g., GeoSLAM Zeb-Revo $49.000 and the trolley based Viametris iMS3D $150.000), but do provide accurate geometric and semantic information.

[1] Source: https://www.aniwaa.com/buyers-guide/3d-scanners/slam-3d-scanners-imms-mobile-mapping/

The method of using point clouds comes with its disadvantages. Extracting the geometry of an indoor space is based on the detection of primitive shapes (e.g., planes, lines, cuboids, rectangles), which means that more complex architectural geometry reconstruction is limited to these primitives (Nikoohemat et al., 2020). Noise, occlusions, sparsity, and variance in the density of the point cloud can cause the environment to look unrealistic as inaccurate data is obtained. The cost of high-end 3D scanners and Indoor Mobile Mapping Systems are also not viable for this research as they are expensive to purchase and utilize. Lower-end variants of these systems are more viable, but result in lower quality point clouds. Lastly, the process of obtaining a 3D model from a specific indoor space is time consuming. The place in question should be visited with the scanning device, and the obtained 3D point cloud must also be transformed into a 3D model and made VR compatible.

4.1.2 Mobile Devices with LiDAR Technology.

An alternative to expensive 3D scanners and Indoor Mobile Mapping Systems is the use of mobile Light Detection and Ranging (LiDAR) sensor technology. Devices with built in LiDAR technology, such as iPhone 12 Pro and the iPad Pro, are capable or 3D scanning indoor spaces and can be exported for CAD software. However, the quality of these scans is relatively poor. To make it more viable, Magicplan uses the LiDAR data to create 2D floorplans, which in turn can be reconstructed in 3D. When compared to high-end 3D scanners, this solution is significantly cheaper as its starting price is set at €9.99 per month.

4.2 Photographic-based Reconstruction

Another approach to obtaining geometric and semantic information of indoor spaces is implementing photographic-based methods, which can be divided into single-view depth estimation and multi-view depth estimation. *"The main goal of depth estimation is to directly estimate the depth of image pixels for reflecting the real 3D scene observed in an image."* (Kang et al., 2020, p.5). Single-view depth estimation recovers data from a single picture, while multi-view depth estimation uses many overlapping images to obtain data based on the camera parameters and poses.

4.2.1 Single-view Depth Estimation: Panoramic Images.

An example of a single-view depth estimation method is the reconstruction of 3D environments using panoramic images (e.g., Pintore et al., 2021; Tran, 2021; Xu et al., 2017). LayoutNet (Zou et al., 2018) and DuLa-Net (Yang et al., 2019) are deep convolutional neural networks that predict room layouts or semantic 2D floorplans in the ceiling view resp. from a single RGB panoramic image. Both approaches are capable of reconstructing Manhattan layout style (i.e., rectangle-based layouts where walls intersect orthogonally) from a single image, but lack the ability to include 3D models of the furniture and opening features positioned inside the room.

4.2.2 Multi-view Depth Estimation: Photogrammetry.

A multi-view depth estimation approach is photogrammetry. Photogrammetry concerns the process of capturing lots of images from a variety of angles and stitch these images together in dedicated software that uses pattern recognition algorithms. These algorithms identify overlapping parts of multiple images and uses that information to reconstruct an 3D representation of what was captured. Overlapping is paramount when using this method. A major advantage of this method is that images can be taken from a smartphone or with a simple digital camera, so no expensive additional equipment is needed. However, this method is extremely time consuming as between 20 – 250 photos should be shot based on the size of the object. As this technique is most commonly used for reconstruction smaller objects, indoor spaces might require even more images to acquire a decent result. Another major drawback is that white walls or other smooth areas need to manually fixed as this technique has difficulty mapping these areas.

4.3 2D Floorplan Reconstruction

2D floorplans can be used to reconstruct 3D indoor spaces. Silveira et al., (2016) presented a computational model that is capable of procedurally generating three-dimensional interior styles and customized exterior façades. Obtaining geometric information in the form of a 2D floorplan can be obtained through various approaches.

4.3.1 Real-world 2D Floorplans.

Most houses/appartements have their floorplan stored either at an archive online or at the archive at the municipality, which can be requested for view. Although it might be time consuming to obtain these documents, they can be used for 3D reconstruction. In a study conducted by Park & Kim, (2021) 2D raster floorplans are automatically converted into 3D vector models using a combination of deep learning, based on a small training dataset, and rule-based heuristic methods. Raster-to-vector conversion is a method that can transform raster-type floorplans (i.e., resolution-dependent pixels with colour values) to a vector-type floorplan (i.e., resolution-independent mathematical curves) (Liu et al., 2017). As raster-type images are limited to a specific amount of readable information, this transformation to vectors is an important step to be able to use it in computer-aided design (CAD) software. Plan2Scene, a system developed by Vidanapathirana et al., (2021), is capable of transforming 2D floorplan image into a 3D mesh model and uses included associated images of the building to synthesize surface textures, including a graph neural network architecture that is capable of texturing unobserved surfaces.

The system developed by Vidanapathirana et al., (2021) can extract textures and create specific objects. However, this is achieved using neural embedding-based tile-able texture synthesis, texture synthesis for observed surfaces, and texture propagation to unobserved surfaces using graph neural networks. These methods are currently beyond this project's scope, and moreover, most official 2D floorplans do not provide details about furniture placement.

4.3.2 Procedurally Generated 2D Floorplans.

Although not focused on reconstructing specific existing indoor spaces, procedural generation methods, have been developed to solve the problem of 2D floorplan assembly for buildings through various algorithms (Feklisov et al., 2020) such as, tiling (e.g., Green et al., 2019), squarified tree maps (e.g., Andersson, 2019), growth (e.g., Martin, 2006), dense packing (e.g., Koenig & Knecht, 2017), and inside-out. Procedural Generation (PG) refers to the process of generating 'something' algorithmically rather than performing manual design and development, which reducing the cost, time and effort of the development process (Amato, 2017). In practice, this technique has been applied in numerous video games to counter the *'The Mountain of Content Problem'* (Bach & Madsen, 2007).

Procedurally generating furniture is based upon answering two questions (Ringqvist, 2018): What different types of furniture/objects should be placed in the room? Where should these objects be positioned and oriented? Some studies used optimization-based algorithms where the generated floorplan is measured against pre-defined layouts. Merrell et al., (2011) incorporated aesthetic evaluations in their algorithm, Yu et al., (2016) used smooth Bezier curves to calculate and prevent overlapping segments. As these optimization-based algorithms are extremely computationally heavy, real-time use is not advisable. To achieve real-time use a deterministic algorithm using deterministic randomization has been implemented (Andersson, 2019; Germer & Schwarz, 2009). Objects containing attachments points were placed based on their position in a pre-defined hierarchy (e.g., initially a table is positioned, then chairs, then pillows, etc.). Then, objects lower in the hierarchy are placed on these attachment points to fill the room with furniture.

An early adaption of using procedural generation for the generation of architecture is Wonka et al., (2003), who developed a framework for the automatic modelling of exterior architecture where high-level design choices are made through simple parameters. This system makes use of L-systems and shape grammars, both categorized as generative grammars. Shape grammars work in a similar fashion as L-systems as in that rules can be applied recursively to predefined shapes so that new shapes are generated. So as new rules can be applied in each new iteration, the building blocks (i.e., axioms) could have successors with additional features/properties, thus creating details. Another project presents a novel shape grammar called Computer Graphic Architecture (CGA) that is aimed at creating computer generated structures (Müller et al., 2006). This grammar includes production rules that iteratively evolves a design by gradually creating more details. These two algorithms are focussed on the generation of exteriors only, and do not include the generation of interiors.

4.3.3 User-designed 2D Floorplans.

To avoid to process of obtaining official 2D floorplans, self-produced alternatives might present a faster solution for 3D reconstruction of spaces. Several applications offer their users the possibility to create 2D floorplans, including various furniture models and styles, and export them as 3D models usable for CAD software. Examples of these applications are Sweet Home 3D[2], Planner5D[3], floorplanner[4], and pCon planner[5]. These applications are free to use and are capable of producing accurate and realistic 3D models, making this a possible viable solution. The interfaces, however, might be challenging to use as it is not designed for individuals with MBID.

Alternatively, Camozzato et al., (2015) developed a system that is capable of reconstructing building interiors based on hand-drawn building sketches. Although drawn versions might lack accuracy as people might not know the exact dimensions of specific rooms at home, it could still be used as an alternative to obtain 2D floorplans. The walls and openings of the drawn layouts are extracted using image processing, after which their growth-based procedural generation algorithm creates a 2D floorplan based on the input of the user. However, this approach also does not include the recognition and reconstruction of furniture.

4.4 Discussion

To find an answer for **RQ2.1**, three approaches to reconstructing 3D models of indoor spaces were analysed: point cloud-based reconstruction, photographic-based reconstruction, and 2D floorplan-based reconstruction

- **Point cloud-based reconstruction**:

Using 3D scanners or Mobile LiDAR technology accurate reconstruction of large indoor spaces can be created. However, high-quality equipment is expensive, and lower-end alternatives may produce lower quality results, more vulnerable to noise, occlusions, sparsity, and varying density. They may also inaccurately represent furniture due to occlusion issues. Mobile LiDAR technology, like Magicplan, might be a more cost-effective solution, using built-in technology in some mobile devices.

- **Photographic-based reconstruction**:

This approach uses images, often with deep convolutional neural networks, to create 3D models. Current applications, however, are restricted to Manhattan style room layouts and do not include furniture. The method presented by Vidanapathirana et al., (2021) might overcome this furniture drawback. Photogrammetry was identified

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[2] https://www.sweethome3d.com/
[3] https://planner5d.com/
[4] https://floorplanner.com/
[5] https://pcon-planner.com/nl/

as another possible approach, but it can be time-consuming and may yield unrealistic results if improperly mapped areas are not manually corrected.

- 2D floorplan-based reconstruction:

Floorplans can be obtained through several methods, like using existing official 2D floorplans, creating hand-drawn 2D floorplans, or procedurally generating 2D floorplans. The first two approaches may involve either raster-to-vector transformations or image processing to extract usable data from the floorplans. Vidanapathirana et al., (2021)proposed an approach to instantiate furniture, but a simplified method could be more feasible, such as manual furniture positioning and texturing.

Chapter 5. Ideation

The outcome of the ideation phase in creative technology-based projects entails *"a (more) elaborated project idea, together with the problem requirements."* (Mader & Eggink, 2014, p.4). In order to present a more elaborated project idea and its related problem requirements, various activities are conducted. The undermentioned **Chapter 3.1** presents the methodology used during this phase.

5.1 Methodology

In order to acquire a more grounded project idea including a set of specified context-related requirements, a selection of methods is implemented.

5.1.1 Requirement Categories

Setting up a comprehensive list of all-encapsulating requirements is a necessity when developing software, as it functions as a clarification of the stakeholder's demands regarding the functionality, behaviour, and performance of the system. A distinction is made between three requirement categories, each addressing a relevant category in software engineering: *user requirements*, *business requirements*, and *system requirements*, of which the latter has been divided into *functional*- and *non-functional system requirements*:

- *User requirements:* this set of requirements relates to what the intended users should be able to achieve when operating the system and reflect their specific necessities during interaction.
- *Business requirements:* this set of requirements relates to what the organisation, for which the system is being developed, wants to achieve with the system and reflects the specific goals they set.
- *Functional system requirements:* this set of requirements relates to statements or goals that define what the system should do and not do in order to realize the user requirements.
- *Non-functional system requirements:* this set of requirements relates to defining the characteristics and expected user experience of the system, which cover performance, usability, scalability, security, and portability.

5.1.2 Process of Engineering Requirements

The process of identifying and concretising relevant requirements can be broken down into five phases, each including their own set of activities: *elicitation*, *analysis*, *specification*, *validation*, and *management* of requirements (Bourque et al., 1999).

- *Elicitation:* The elicitation of the requirements covers the discovery and gathering of specific requirements from stakeholders and other sources. In order for the discovery process to commence, a stakeholder analysis should be conducted to identify the relevant groups related to this research. Various activities could be conducted during this phase, such as expert interviews, questionnaires, use cases, and interface analyses.

- *Analysis:* The analysis of the requirements covers the process of understanding the gathered information and represent it as sets of requirements.
- *Specification:* The specification of the requirements covers the representation and storage of the acquired requirements in an orderly fashion in order to support communication to relevant stakeholders and support requirement alteration.
- *Validation:* The validation of the requirements covers the confirmation that a valid set of requirements has been specified. This contains discussions with stakeholders and the prioritization of the requirements to reach a common understanding with stakeholders on the importance of each desired requirement.
- *Management:* The management of the requirements covers updating the specified set of requirements as they are prone to change during the duration of the development of the system.

5.1.3 Approach

In order to elicit user- and business requirements a stakeholder analysis will be conducted to identify the relevant parties connected to this research. Stakeholders can be defined as *"any group or individual who can affect or is affected by the achievement of the organization objectives"* (Freeman, 2010, p.53) and a major factor of success of software is based on the appropriate selection of stakeholders (Razali & Anwar, 2011). The analysis process and outcomes can be read in Chapter 5.2: Stakeholder Analysis.

With the stakeholders identified, various activities will take place to stimulate the elicitation of desired requirements. An extensive literature research was conducted on the characteristics of the users and aims to highlight the identified internal (i.e., limitations of technology use due to the characteristics of user) and external barriers (i.e., external factors that obstruct the user experience of the technology) to the use of technology. This provides us with an overview on possible relevant user requirements when it comes to developing software application for individuals of the identified target group. The outcomes of the literature review regarding this topic can be read in Chapter 3.2: Barriers to Technology Use by Individuals with MBID.

The literature research provides us with a better understanding of the inner workings of people with MBID. The next step is to focus on identifying relevant requirements for each of the categories previously presented. The outcomes of the identified business-, user-, functional-, and non-functional requirements can be read in Chapter 5.3: Requirement Elicitation and Analysis.

The various types of technology related to the context of this research (i.e., indoor space 3D reconstruction methods) are limited, therefore a strengths and weaknesses analysis was conducted to identify their suitability for this research. Two sets of factors were selected: accuracy-related factors and user experience -related factors. The accuracy-related factors focus on identifying the overall capabilities of extracting information from indoor spaces, whereas the user experience-related factors highlight the extent to which individuals of the target group are capable of operating the reconstruction methods. Initially, a factor selection procedure is performed where (non-) functional system requirements are identified and implemented as the accuracy-related factors, and previously identified user- and business requirements are implemented as the user experience -related factors. The outcomes of the analysis serve multiple purposes. By reflecting the requirements on the already existing reconstruction methods, we can acquire a clearer overview on the possibilities of using said methods within this context. It also supports the decision-making during the prioritization process as it highlights the importance of specific requirements. Besides its usefulness during the requirement engineering process, it provides us with a more in-depth view on this novel exploration. Recommendations provided after the analysis act as the backbone of the proposed system. The process and outcomes of this analysis can be found in Chapter 5.4: Strengths and Weaknesses Analysis of Reconstruction Methods.

Now that a more elaborated picture on the strengths and weaknesses of the discussed approaches, additional requirements will be. Furthermore, the complete set of requirements will be discussed and the MoSCoW Prioritization method will be used to assess the priority of the requirements (Clegg & Barker, 1994). This method is an often-used asset by designers and developers to acquire clear prioritization of a range of requirements or functionalities given the stakeholder's needs and the time constraints of the developer. An overview of all prioritized requirements can be found in Chapter 5.5: Requirement Specification and Validation.

The information acquired in the previous activities function as the foundation for presenting an elaborated project idea. Using this information, a proposal will be made for a system that addresses all identified requirements. The system proposal can be read in Chapter 5.6: System Proposal.

5.2 Stakeholder Analysis

Stakeholders can be defined as *"any group or individual who can affect or is affected by the achievement of the organization objectives"* (Freeman, 2010, p.53). Tovar & Pacheco, (2006) conducted a comparative analysis of four approaches and presented relevant conclusions. To begin with, it is important to appropriately assign the roles of the stakeholders and ensure an adequate classification of their requirements. After that, the identified stakeholders need to be: (1) characterized by providing suitable characterisation descriptions, (2) ensuring the understanding of their requirements, and (3) include explanations of their roles and interactions. Three types of information are therefore required: *"information concerning each individual stakeholder with their roles and profiles (skills), information concerning their interactions within the software project (requirements), and information concerning their interactions with other stakeholders."* (Tovar & Pacheco, 2006, p.507).

As an outcome of an individual brainstorm, three types of stakeholders have been identified: *The organisation addiction treatment centre Tactus, staff of Tactus,* and *individuals with MBID admitted to Tactus*.

- Stakeholder 1: The organisation addiction treatment centre Tactus
  As specialists in addiction treatment, Tactus offers support and guidance to adolescent and adult individuals who suffer from any type of addiction (e.g., substance use or gambling), even in combination with other complications (i.e., dual-diagnosis). Tactus as an organisation has an interest in the development and implementation of novel technologies of which existing treatment approach could benefit (e.g., introducing virtual reality in their CBT treatment methods). This research can be seen as a development of novel technology impacting treatment methods, indicating their stake and relevance in this project. The requirements set by Tactus are identified later on and can be categorized within the *business requirements*.

- Stakeholder 2: Individuals with MBID admitted to Tactus [EU1]
  The main end-users of the system will be individuals with MBID that have been admitted to an addiction treatment centre, which in this context is Tactus. Individuals from this stakeholder category could suffer from various substance use disorders; however, the focus of this research is on individuals with alcohol use disorder. Because of their characteristic of having an intellectual disability, specialized approaches for their addiction treatments should be implemented in order to address the related internal and external barriers. It is therefore paramount to identify the specifics of these barriers in order to be able to address them in the project idea and as *user requirements*. This stakeholder group will be interacting with other stakeholders in the form of the staff present at Tactus; however, the amount of assistance this group shall receive is yet to be discussed and needs to be investigated.

- Stakeholder 3: Staff of Tactus [EU2]
  The other end-users, although less prominently interacting with the system, are treatment providers of other qualified staff members of Tactus. Individuals from this stakeholder group provide treatment care to individuals that have been admitted to Tactus for (poly)-substance use disorders or other types of addiction, including dual-diagnosis. It is important to assess the extent to which individuals of this stakeholder group will be present when operating the system, as they can provide suitable guidance in this process. Additional user requirements should be identified for these stakeholders.

5.3 Requirement Elicitation and Analysis

Now that the stakeholders have been identified, the elicitation process of their associated requirements will commence. The following sections focus on identifying relevant requirements for each of the categories presented in Chapter 5.1.1.

5.3.1 Business Requirements Elicitation

Preliminary research conducted by van Aggelen, (2017) explored how VR can support SUD treatment for people with intellectual disabilities. The research conducted in this study expands upon this previously conducted research and therefore shares certain similar business requirements. During this research, an interview with *"key players at Tactus regarding the development of new E-health technologies"* was and organised, who, because of their function, *"can therefore represent the organization of Tactus"* (p.26). The goal of this interview was to identify various relevant business requirements and gain insights in the inner workings of the organisation. Seven business requirements were identified during this method, which will be analysed to find their relevance in this research. In additional discussions held with experts in this field of the seven identified business requirements by van Aggelen, (2017), four are found to be also relevant in this research:

- *Development and Maintenance Cost:* the costs of the development and maintenance of the final product should be within a to be determined budget.
- *Supplementary Technology Cost:* the costs of the purchase of additional software and hardware to support the final product should be within a to be determined budget.
- *Portable accessibility:* the final product should be capable of being easily setup in any room located in the organisation, which should limit the amount of hardware needed.
- *Safety:* the generated environment is reviewed as safe by the qualified Tactus treatment providers before the clients use it.

5.3.2 User Requirements Elicitation

Two user groups have been identified during the stakeholder analysis: individuals with MBID that have been admitted to an addiction treatment centre (EU1) and treatment providers employed at addiction treatment centres (EU2). The user requirements of EU1 will be acquired by analysing literature research previously conducted. Besides analysing existing literature, discussions with experts in this field provide additional information for eliciting user requirements for both EU1 and EU2.

In order to answer the main research question, a system will be developed that is capable of acquiring the necessary geometric and semantic information from indoor spaces, use that information to generate a 3D reconstruction, and port the reconstruction to VR. Information of indoor spaces has been sub-divided into two categories: geometric information and semantic information. As discussed in Chapter 4.3, Silveira et al., (2016) made a distinction between these two architectural information types as they provide an all-encapsulating structure for reconstructing architecture. Analysing the accuracy of both information extraction types are of the essence, because of their direct relation to inciting 'presence' in virtual environments. Presence has been defined as the subjective experience of being in one place or environment, even when one is physically present in another, (Witmer & Singer, 1998), or when put in the context of virtual environments as the sensation of being in the place presented in an IVE (Nash et al., 2000). Preliminary research has indicated that the identified factor of 'experienced realism' contributes to increased feelings of presence (Paulissen, 2021), indicating the importance of an accurate reconstruction of an indoor space. In order to achieve higher levels of presence, the reconstructed environment should be of relatively high accuracy, which results in the following user requirements:

- *Information acquisition:* EU1 should be able to acquire/input the geometric and semantic information from an indoor space with relatively high accuracy.
- *VR immersion:* EU1 should be able to view the reconstructed indoor space in VR.

Chapter 3.2.2 discussed the various internal and external barriers people with MBID face when interacting with technology. In order to have EU1 fluently use the system, no obstruction should be present when operating the system autonomously; therefor, two user requirements have been formulated:

- *Internal barriers:* EU1 should be able to fluently interact with the system without being obstructed due to internal barriers.
- *External barriers:* EU1 should be able to fluently interact with the system without being obstructed due to external barriers.

During discussions with experts in this field, including a representative of Tactus, an additional business requirement was identified. This requirement relates to the degree to which treatment providers of Tactus, or other forms of assistance, should be present when individuals of EU1 are operating the system. During the discussions, three levels of required assistance were determined: *complete assistance* (i.e., where treatment providers are present in every aspect of EU1's life, including visitation of the client's living space), *moderate assistance* (i.e., where treatment providers are able to help EU1 when present in addiction treatment centres, such as Tactus), and *no assistance* (i.e., the client has to perform all procedures independently). It was concluded that people of EU2 will be able to moderately assist people of EU1 during the interaction with the system, but that only people of EU1 should operate the system. The Self-Determination Theory suggests that individuals are more motivated to grow and change behaviour when their psychological needs of autonomy, competence and relatedness are met (Deci & Ryan, 2012); hence, having people of EU1 solely operate the system is considered beneficial. This requirement is therefore formulated as:

- *Required assistance:* EU2 should be able to help EU1 during the interaction with the system; however, should not participate in operating the system.

Expert consultations also highlighted the importance of incorporating legal requirements into the system design. Given that the system could deal with sensitive user data, it's essential to comply with the AVG (Algemene Verordening Gegevensbescherming), the Dutch equivalent of the General Data Protection Regulation (GDPR). This legal framework ensures that the personal data of the users is handled responsibly. As such, the following requirement is formulated:

- *Data Privacy Compliance:* The system should be designed and operated in full compliance with the AVG, ensuring the secure handling, storage, and processing of user data.

In addition, the system's use in a healthcare context requires the compliance to the Medical Device Regulation (MDR). This EU regulation sets out detailed requirements to ensure the safety of medical devices. This regulation would apply since the developed system could be classified as a medical device, given its applied context. The following requirement is formulated:

- *Medical Device Compliance:* The system should be developed and maintained in line with the requirements stipulated in the MDR, ensuring its safety and effectiveness as a healthcare tool.

5.3.3 Functional System Requirements Elicitation

In order to fulfil the abovementioned user requirements, specific functionality should be built into the system. In order to fulfil the user requirement of 'information acquisition', specific geometric and semantic information should be extracted from an indoor space. The functional system requirements related to the acquisition of geometric information from indoor spaces are formulated as follows:

- *Spatial dimensions:* the system allows for the acquisition of the spatial dimensions of an indoor space with relatively high accuracy.
- *Fenestration position:* the system allows for the acquisition of the position of the fenestration features of an indoor space with relatively high accuracy. Fenestration encompasses all architectural features, such as doors, windows, and other openings.
- *Furniture position:* the system allows for the acquisition of the position of furniture located in an indoor space with relatively high accuracy.

The functional system requirements related to the acquisition of semantic information from indoor spaces are formulated as follows:

- *Interior surface textures:* the system allows for the acquisition of the interior surface textures of an indoor space with relatively high accuracy.
- *Fenestration characteristics:* the system allows for the acquisition of the characteristics of the fenestration features of an indoor space with relatively high accuracy.
- *Furniture characteristics:* the system allows for the acquisition of the characteristics of furniture located in an indoor space with relatively high accuracy.

Once the information has been acquired, the system should be able to generate a 3D reconstruction of an indoor space and port this environment to an HMD. This results in the following functional system requirements:

- *Generation process:* the system allows for the generation of a 3D reconstruction of an indoor space using the acquire geometric and semantic information.
- *VR porting:* the system allows for the 3D reconstruction of an indoor space to be ported to an HMD.

5.3.4 Non-Functional System Requirements Elicitation

Some relevant non-functional system requirements have been identified during the elicitation process.

- *Language:* the language used in the system should be in Dutch.
- *Protected storage:* the reconstructed indoor spaces should be safely stored so that no private information can be shared in public.

5.4 Strengths and Weaknesses Analysis of Reconstruction Methods.

In Chapter 4 we explored various methods that are capable of extracting geometric- and semantic information from 3D indoor spaces and how these methods reconstruct these spaces. The identified methods are:

(1) High-end 3D scanners and Indoor Mobile Mapping Systems.
(2) Mobile LiDAR applications.
(3) Single-view Depth Estimation: Panoramic images.
(4) Multi-view Depth Estimation: Photogrammetry.
(5) Real-world 2D floorplans.
(6) User-designed 2D floorplans.

The goal of this analysis is to identify the strengths and weaknesses of each reconstruction method in regard to the previously identified requirements and rather to identify the methods' strong and weak points regarding a selection of context-specific factors, which are derived from the previously stated requirements. This analysis will also function as the foundation of an individual brainstorm session with the goal of presenting a system proposition.

The factors have been divided into two categories: *accuracy-related factors*, which highlight the extent to which the reconstruction methods are capable of extracting accurate geometric and semantic information from indoor spaces, and *user experience-related factors*, which highlights the usability and accessibility of the reconstruction methods in relation to the stakeholders.

5.4.1 Factor selection.

As mentioned, the selection of factors will be derived from the previously presented requirements. The accuracy-related factors are derived from the set of functional system requirements related to acquiring geometric and semantic information from indoor spaces. Table 1 contains a list of the selected accuracy-related factors including a description on the contents of each factor. The general factors of the user experience -related factors are based on three business requirements (development and maintenance cost and supplementary technology cost are grouped), whereas the target group-specific factors are related to the user requirement of internal barriers. In order to find out the extent to which the operability of a reconstruction method is hindered by internal barriers of EU1, the five domains of cognitive functioning discussed by Carroll, (1993) will be used as factors. Table 2: Selection of user experience-related factors.

contains a list of the selected user experience -related factors including a description on the contents of each factor.

	Factor	Description
Geometric Information Extraction	Spatial Dimensions	The spatial dimensions of an indoor space are represented by its spatial extent (i.e., length, width, and height). The spatial dimensions are the foundation of the reconstruction process; therefore, this factor analyses the extent to which a reconstruction method is capable of accurately extracting the spatial dimensions of an indoor space.
	Fenestration Position Extraction	The term fenestration encompasses the architectural features of doors, windows, and other openings of indoor spaces. This factor analyses the extent to which a reconstruction method is capable of accurately extracting the position (i.e., middle point of the feature) of the fenestration features of an indoor space.
	Furniture Position Extraction	This factor analyses the extent to which a reconstruction method is capable of accurately extracting the position of present furniture in an indoor space.
Semantic Information Extraction	Interior Surface Texture Extraction	Interior surfaces (i.e., walls, floor, and ceiling) all have distinct textures in indoor spaces. This factor analyses the extent to which a reconstruction method is capable of accurately extracting the textures of the interior surfaces on an indoor space.
	Fenestration Characteristics Extraction	Fenestration types have distinct characteristics (i.e., textures, shapes, and dimensions). This factor analyses the extent to which a reconstruction method is capable of accurately extracting these characteristics.
	Furniture Characteristics Extraction	Different types of furniture have distinct characteristics (i.e., textures, shapes, and dimensions). This factor analyses the extent to which a reconstruction method is capable of accurately extracting these characteristics.

Table 1: Selection of accuracy-related factors.

	Factor	Description
General Factors	Development and Maintenance Cost	The cost of the proposed reconstruction process is an important factor, as the future system should be affordable for organisations such as Tactus. Approaches that are less expensive are more advantageous than approaches that cost significantly more.
	Required assistance from non-target group individuals.	Some reconstruction methods might require assistance from people outside of the target group. Some methods might require experts in a specific field, or require multiple people in order to operate the system.
	Additional software/hardware requirements	A reconstruction method might require additional software or hardware in order to make work. Highlighting these requirements provides a clearer picture on the complexness of a reconstruction method.
Target Group-specific Factors	Language, communication, and auditory reception.	This domain refers to the abilities that are associated with the conceptual domain of adaptive functioning and relate to the competences of an individual's vocabulary, grammar, reading comprehension, reading speed, and oral production ability.
	Reasoning, working memory, and cognitive speed	This domain refers to the ability to process information. Cognitive speed refers to the ability to rapidly process information accurately, whereas working memory *"is a basic cognitive mechanism (or set of mechanisms) that is responsible for keeping track of multiple task-related goals and subgoals, or integrating multiple sources of information."* (Miyake & Shah, 1997, p.1). Carroll, (1993) discussed three main independent dimensions of ability in reasoning.
	Memory and learning	This domain refers to the ability to retain or forget a memory of the outcomes of learning processes.

Visual perception abilities	This domain refers to abilities *in "searching the visual field, apprehending the forms, shapes, and positions of objects as visually perceived, [and] forming mental representations"* (Carroll, 1993, p.304). It concerns the ability to quickly manipulate visual patterns, or apprehend and identify visual patterns when the patterns are disguised in some way.

Table 2: Selection of user experience-related factors.

5.4.2 Strength and Weaknesses of 3D Indoor Reconstruction Methods.

The selected factors will function as the foundation of this strengths and weaknesses analyses. Each reconstruction method will be analysed on these factors to indicate their overall strengths and weaknesses. In order to highlight their overall strength regarding the factors, a custom-made 5-point ordinal scale has been constructed. This 5-point indication scale can be seen in **Table 3.**

Scale indicator	Description
++	The reconstruction method is beneficial concerning this factor.
+	The reconstruction method is somewhat beneficial concerning this factor.
+/-	The reconstruction method is not beneficial nor unfavourable concerning this factor.
-	The reconstruction method is somewhat unfavourable concerning this factor.
--	The reconstruction method is particularly unfavourable concerning this factor.

Table 3: 5-Point scale used in the strength and weaknesses analysis.

It is important to note that the indications are subjective and based on my understanding and research, as there is no quantitative approach to indication strength and weaknesses in such a context as this research.

The outcomes of the analysis can be found in the tables found below. **Table 4** discusses the accuracy-related factors of point cloud-based reconstruction methods and **Table 5** discusses its user experience -related factors. **Table 6** discusses the accuracy-related factors of photographic-based reconstruction methods and **Table 7** discusses its user experience -related factors. **Table 8** discusses the accuracy-related factors of floorplan-based reconstruction methods and **Table 9** discusses its user experience -related factors.

5.4.3 Discussion of the Strengths and Weaknesses analysis

This section discusses the outcomes of the analysis and discusses notable findings. The findings will be presented as relevant considerations for the coming brainstorm session focused on identifying possible solutions.

Accuracy-based factors.

Most reconstruction methods were capable of accurately extracting the information regarding spatial dimensions, except for user-designed floorplans, as they rely on the imaginative capabilities of the user. In spite of this, additional procedures could be implemented to improve the overall accuracy of the extracted information (e.g., prior provision of easy-to-use measuring tools). The analysis highlighted the necessity of additional procedures in order to extract both the position and the characteristics of both fenestration and furniture. Semantic labelling approaches (e.g., Koppula et al., 2011) and deep convolutional networks (e.g., Luo et al., 2019) can used for object recognition and reconstruction; however, because of their complex technological nature other methods might become more approachable. Manually indicating fenestration and furniture positions on a digital floorplan (either obtained through manual design, or obtained through transforming extracted spatial dimension data) could seem like a more approachable procedure; however, it comes with its own caveats. Additional procedures should be included to insert fenestration and furniture objects with specific characteristics on the indicated position. Selecting models from a pre-defined dataset (e.g., Zou et al., 2018) or by obtaining models from photogrammetry or LiDAR scans. This relates to the finding that there are numerous methods for obtaining accurate geometric and semantic information on indoor spaces. For example, combining real-world floorplans (spatial dimensions), user-designed floorplans (fenestration and furniture positions and interior surface texture indication), and LiDAR scans (fenestration and furniture characteristics) could provide the user with an accurate reconstruction.

User experience-related factors.
Commercially available image capturing, and 3D scanning equipment are often not developed with MBID characteristics in mind. Cognitive limitations in reasoning, working memory, and cognitive speed, memory and learning, and visual perception abilities hamper the use of such technologies for people with MBID. Unclear textual indications that they have initialized the capturing process is a barrier related to limitations in sequential reasoning and limitations in auditory reception Wehmeyer et al., (2004). For instance, when pressing the button for image capturing initiation some devices might make a confirming sound; however, *"it is difficult to discern their meaning"* (p.9). Additionally, most methods are not specifically linear in nature (i.e., presence of multiple interface choices simultaneously), resulting is operational difficulties and hindrance in technology use (Wehmeyer et al., 2004). Most hardware/software included in this analysis require memory and generalisation capabilities (e.g., metaphorical symbols representing functions, placement of specific button) in order to operate said systems. This external barrier must be prominently addressed, especially when institutions desire independent operability by the target group. The analysis indicated, however, that most methods do require some form of assistance, be it expert assistance for 3D scanner or IMMS operability or assistance in operating mobile devices during LiDAR scans and panoramic capturing for example.

	Factors \ Methods	High-end 3D scanners and Indoor Mobile Mapping Systems.	Mobile LiDAR Applications.
Geometric Information Extraction	Spatial Dimensions	++ IMMS systems, such as the Viametris iMS3D, are capable of providing point clouds with an accuracy up to 3cm (Maboudi et al., 2018), while the GeoSLAM ZEB-REVO RT and the GreenValley LiBackPack C50 have an accuracy up to 5 cm (Salgues et al., 2020).	++ The point clouds obtained from LiDAR sensors of the Apple iPhone 12 Pro have an absolute accuracy of ± 10 cm for objects with the dimensions of up to 130 × 15 × 10m (Luetzenburg et al., 2021), while the iPad Pro was found to contain an accuracy of 4cm when used to reconstruct a detailed indoor space (Spreafico et al., 2021).
	Fenestration Position Extraction	+/- A 6-step method proposed by Adan & Huber, (2011) was capable of correctly detecting 93.3% of the openings in indoor spaces from point clouds; however, this mostly applies to rectangular openings and has difficulties extracting closed doors.	+ Precise positional data of fenestration requires semantic labelling methods; however as using mobile devices (e.g., iPad Pro) can be utilized dynamically the fenestration objects will be included automatically.
	Furniture Position Extraction	+ Extracting furniture positions requires additional methods, such as combining point cloud data with RGB images of the indoor spaces and implement semantic labelling methods to identify specific objects. Koppula et al., (2011) achieved an accuracy of 73.38% in labelling 17 object classes for home scenes.	+ Precise positional data of furniture requires semantic labelling methods; however as using mobile devices (e.g., iPad Pro) can be utilized dynamically the furniture objects will be included automatically.
Semantic Information Extraction	Interior Surface Texture Extraction	+ 3D scanners and IMMS often include other sensors for texture extraction. When this is not the case, external imagery can be implemented to obtain textures (Nikoohemat et al., 2020). Static scanners are more prone to inaccuracies due to occlusion and require addition algorithms for recalculation.	+ LiDAR depth data is merged with the accompanying colour (RGB) data using AI to obtain textured surfaces (Vogt et al., 2021).
	Fenestration Characteristics Extraction	+/- The fenestration extraction approach presented by Adan & Huber, (2011) resulted in an accuracy of 2.5cm for 36% of the opening's dimensions. 3D scanners and IMMS often include other sensors for texture extraction. When this is not the case, external imagery can be implemented to obtain textures (Nikoohemat et al., 2020). Static scanners are more prone to inaccuracies due to occlusion and require addition algorithms for recalculation.	+ The LiDAR technology of an iPad Pro extracts point distances (i.e., distance between points in a point cloud) with an accuracy between 0.9cm (max detail) and 5.2cm (max area) when scanned 1 meter from the target. This changes to 3.3cm (max detail) and 19.1cm (max area) when scanned from 4 meters (Spreafico et al., 2021). LiDAR depth data is merged with the accompanying colour (RGB) data using AI to obtain textured objects (Vogt et al., 2021).
	Furniture Characteristics Extraction	+ 3D scanners and IMMS often include other sensors for texture extraction. When this is not the case, external imagery can be implemented to obtain textures (Nikoohemat et al., 2020). Static scanners are more prone to inaccuracies due to occlusion and require addition algorithms for recalculation.	+ The LiDAR technology of an iPad Pro extracts point distances (i.e., distance between points in a point cloud) with an accuracy between 0.9cm (max detail) and 5.2cm (max area) when scanned 1 meter from the target. This changes to 3.3cm (max detail) and 19.1cm (max area) when scanned from 4 meters (Spreafico et al., 2021). LiDAR depth data is merged with the accompanying colour (RGB) data using AI to obtain textured objects (Vogt et al., 2021).

Table 4: Accuracy-related factors of point cloud-based reconstruction methods.

	Methods Factors	High-end 3D scanners and Indoor Mobile Mapping Systems.	Mobile Devices with LiDAR Technology.
General Factors	Operational costs.	-- Purchasing these types of scanners will be extremely expensive (e.g., GeoSLAM Zeb-Revo $49.000 and the trolley based Viametris iMS3D $150.000). Hiring an indoor scanning company might be more feasible, but comes with its own accessibility issues.	+ Mobile devices with LiDAR technology are relatively cheap (e.g., iPhone Pro $999, iPad Pro from $799). Depending on the software downloaded additional costs are added; however, these are relatively cheap (e.g., $39/month for SiteScape).
	Additional software/ hardware requirements	-- 3D scanners or IMMS are needed, as well as a computer running specific software to transform the point cloud (and additional data) into a 3d environment.	+ Besides the need of purchasing a mobile device with LiDAR technology built-in, various applications that use LiDAR technology should be acquired (e.g., Canvas[6] and SiteScape[7]).
	Required assistance from non-target group individuals.	-- Requires expert assistance to setup and utilize the scanning equipment and might require assistance in using the reconstruction software.	+/- Depending on the cognitive capabilities of the client, assistance is required to make a scan of the indoor space as existing applications are not designed for people of the target group.
Target Group-specific Factors	Language, communication, and auditory reception	+/- The scanning equipment will most likely not be operated by individuals from the target group.	+ SiteScape and Canvas do require the user to use a built-in virtual keyboard to enter the name of the scan.
	Reasoning, working memory, and cognitive speed	+/- The scanning equipment will most likely not be operated by individuals from the target group.	+/- The SiteScape applications don't give clear textual indications that they've initialized the capturing process; a barrier related to limitations in sequential reasoning. Canvas does show either the text "Start" or "Done". Both applications do display a limited number of options simultaneously, which is beneficial to the target group; whereas applications like MagicPlan[8] present too many options at the simultaneously.
	Memory and learning	+/- The scanning equipment will most likely not be operated by individuals from the target group.	+/- The SiteScape and Canvas application do rely on the user's memory and generalisation capabilities of symbols representing functions (e.g., red dot to start filming in SiteScape, '?' for help). Canvas does rely less on this as they display "Start" or "Done" text to start capturing.
	Visual perception abilities	+/- The scanning equipment will most likely not be operated by individuals from the target group.	+/- Applications, such as SiteScape and Canvas, indicate what areas have been captured by displaying a coloured vertex grid as an indication. This might distract the user from the process of dynamically scanning an indoor space; or could operate as a simple and clear indicator (depending on the user). The use of touchscreen technology is extremely useful for the target group, because of their direct cause effect function.

Table 5: User experience -related factors of point cloud-based reconstruction methods.

[6] Canvas: https://apps.apple.com/us/app/canvas-lidar-3d-measurements/id1169235377
[7] SiteScape: https://www.sitescape.ai/
[8] MagicPlan: https://www.magicplan.app/

	Methods Factors	Single-view Estimation: Panoramic Images	Multi-view Estimation: Photogrammetry
Geometric Information Extraction	Spatial Dimensions	+ The LayoutNet algorithm achieves an average of 71.31% of 2D IoU (i.e., the amount of overlap between the predicted and ground truth bounding box) (Zou et al., 2018); whereas DuLa-Net achieves an average of 77.87% of 2D IoU (Yang et al., 2019), and Led2-net achieved an average of 86.74% (Wang et al., 2021). These algorithms, however, are limited to Manhattan-style spaces.	++ An algorithm presented by Hirose, (2012) achieved an average error margin of 8.8mm with a maximum error of 22.0mm. Bao et al., (2014) achieved a 93.5% overall accuracy on room layout estimation of multiple images.
	Fenestration Position Extraction	- Most algorithms solely focus on extracting the spatial layout of panoramic images; however, doors and windows will be textured on walls without their identification. Semantic labelling algorithms should in theory be able to extract their position. No studies have implemented this approach however.	+/- Although not explicitly mentioned, Bao et al., (2014) did extracted main non-plane related objects, which could include fenestration objects. If so, they were reconstructed with 86% completeness. and had an estimation accuracy of 59%. Hirose, (2012) depends on manual addition of fenestration aspects.
	Furniture Position Extraction	- Most algorithms solely focus on extracting the spatial layout of panoramic images; however a few attempted furniture detection. Luo et al., (2019) implemented deep convolutional networks for object detection, and had an average positional error margin of 12cm. This approach is dependent from the objects included into the training of the network.	+/- Although not explicitly mentioned, Bao et al., (2014) did extracted main non-plane related objects, which could include fenestration objects. If so, they were reconstructed with 86% completeness. and had an estimation accuracy of 59%.
Semantic Information Extraction	Interior Surface Texture Extraction	+ Most estimation algorithms use RGB panoramic images as their data. These images already include the textures of the interior surfaces; however, are often occluded due to furniture positioned in front of it. Additional algorithms could be implemented to detect these occlusions and retexture these to the correct interior surface texture.	+ Interior surface textures are extracted, but are prone to occluded textures of furniture or objects posed in front of the surfaces. Additional algorithms could be implemented to detect these occlusions and retexture these to the correct interior surface texture.
	Fenestration Characteristics Extraction	+ Depending on the present occlusion of the panoramic images, fenestration characteristics are extracted accurately.	+ Although not explicitly mentioned, Bao et al., (2014) did extracted main non-plane related objects, which could include fenestration objects. If so they were reconstructed with 86% completeness and had an estimation accuracy of 59%. Hirose, (2012) depends on manual addition of fenestration aspects.
	Furniture Characteristics Extraction	+/- Although furniture detection algorithms are improving significantly, the reconstruction method is most commonly performed by selecting models from a pre-defined dataset (e.g., Zou et al., 2018). .	+ Bao et al., (2014) were capable of detecting the position and semantics of objects (i.e., 86% completeness object reconstruction).

Table 6: Accuracy-related factors of photographic-based reconstruction methods.

	Methods / Factors	Single-view Estimation: Panoramic Images	Multi-view Estimation: Photogrammetry
General Factors	Operational costs.	+ Panoramic images can be captured through various approaches. Current smartphones have incorporated functions for panoramic capturing, but 360° cameras could also be used (e.g., Eufy by Ankor $50 and Insta360 One X2 $500). Software for information extraction is not commercially available, but can be downloaded for free.	+ The images can be captured through various approaches. Either smartphones, digital cameras, or other image capture devices can be used.
	Additional software/ hardware requirements	+ A smartphone or 360° camera is required, as well as software containing the information extraction algorithms.	+ A smartphone or other image capture devices is required, as well as software capable of transforming these images into a 3D environment.
	Required assistance from non-target group individuals.	+/- Users could be able to independently operate the hardware, but the presence of assistance would be advised. No commercialised software exists for this purpose, so when developed, target group necessities can be incorporated.	+/- Users could be able to independently operate the hardware, but the presence of assistance would be advised. No commercialised software exists for this purpose, so when developed, target group necessities can be incorporated.
Target Group-specific Factors	Language, communication, and auditory reception	+ Some 360 cameras use voice control for capture activation, which could be barrier; however, most cameras additionally include a button, but differ in their function indication. Considering the software is privately developed, the needs of the target group should have been considered (concerns all target-group specific factors).	+ Most cameras include a button to take a photo, but differ in their function indication. Considering the software is privately developed, the needs of the target group should have been considered (concerns all target-group specific factors).
	Reasoning, working memory, and cognitive speed	+/- Smartphones often clearly indicate how the camera should be rotated when operating; however, the combination of directional indication and the dynamic movement of the camera could be a barrier for some (the limitation in sequential reasoning is a major barrier in most capturing hardware). A limited number of options is presented simultaneously, which is beneficial to the target group.	+ Smartphones and other cameras often clearly indicate how the camera should be operated (the limitation in sequential reasoning is a major barrier in most capturing hardware). A limited number of options is presented simultaneously, which is beneficial to the target group.
	Memory and learning	+/- Most image capturing devices rely on the user's memory and generalisation capabilities of symbols representing functions.	+/- Most image capturing devices rely on the user's memory and generalisation capabilities of symbols representing functions.
	Visual perception abilities	+/- Indication is presented on what areas have been captured, which might distract the user from the process of dynamically scanning an indoor space; or could operate as a simple and clear indicator (depending on the user).	- Understanding where specific images should be taken in order to obtain the most accurate results, requires visual perception on what parts of the indoor space have been captured or still need to be captured. This might become a major barrier when not clearly indicated.

Table 7: User experience -related factors of photographic-based reconstruction methods.

	Methods / Factors	Real-world 2D Floorplans	User-designed 2D Floorplans
Geometric Information Extraction	Spatial Dimensions	++ Real-world floorplans contain the exact spatial dimensions on an indoor space; however, depending on the format (e.g., paper, digital) additional steps are required to extract this information. When on paper, image processing approaches are necessary, and when digitally delivered, steps are required to transform the information into CAD-ready information. Many studies succeeded in extracting the spatial dimensions accurately (e.g., Park & Kim, 2021; Vidanapathirana et al., 2021)	+/- The method of obtaining user-designed floorplans can vary. Users can draw a floorplan of an indoor space digitally (e.g., use of tablet with specially designed software or non-digitally like pen and paper), recreate it using specific building materials (e.g., LEGO, wooden blocks), or recreate it in a video game. All these approaches require additional algorithms for the transformation into CAD-ready 2D floorplans. A major barrier is that it's based on the imaginative capabilities of the user to reimage the room, resulting in possible inaccurate spatial dimension information. Additional measures could be included to minimize the inaccuracy.
	Fenestration Position Extraction	++ Real-world floorplans contain the exact fenestration positions, depending on the format (e.g., paper, digital) additional steps are required to extract this information.	+ When designing floorplans, the position of fenestration could be easily included; however, the accuracy of the position could be limited, meaning in the necessity of additional measures.
	Furniture Position Extraction	- Real-world floorplans don't contain the exact furniture position. These positions should be manually included; either before or after the information extraction phase.	+ When designing floorplans, the position of furniture could be easily included; however, the accuracy of the position could be limited, meaning in the necessity of additional measures.
Semantic Information Extraction	Interior Surface Texture Extraction	- Real-world floorplans don't contain information on interior surface textures. These textures should be manually included.	+ When designing floorplans, the texture of the interior surfaces could be easily included; however, a selection must be made from an assortment of textures, which could result in inaccuracies as certain textures might not be included into the assortment.
	Fenestration Characteristics Extraction	- Real-world floorplans don't contain information on fenestration characteristics. These characteristics should be manually included.	+ When designing floorplans, the characteristics of fenestration could be easily included; however, a selection must be made from an assortment of fenestration characteristics, which could result in inaccuracies as certain textures or characteristics might not be included into the assortment.
	Furniture Characteristics Extraction	- Real-world floorplans don't contain information on fenestration characteristics. These characteristics should be manually included.	+ When designing floorplans, the characteristics of furniture could be easily included; however, a selection must be made from an assortment of furniture characteristics, which could result in inaccuracies as certain textures or characteristics might not be included into the assortment.

Table 8: Accuracy-related factors of floorplan-based reconstruction methods.

	Methods / Factors	Real-world 2D Floorplans	User-designed 2D Floorplans
General Factors	Operational costs.	+ The municipality archive often contains the floorplans of the buildings of the city; however, not all floorplans will be present. The costs of requesting these floorplans differ from being free to a few euros.	+ The costs depends on the selected approach. Physical objects come with their independent costs, while digitally designed floorplans require a tablet or computer.
	Additional software/ hardware requirements	+ Transforming the real-world floorplan into a CAD-ready floorplan requires image capture hardware and software containing image processing functions in case of physical floorplans, or require solely specific software for the transformation process.	+ The requirements depend on the selected approach. Image capture hardware and software containing image processing functions in case of physical approaches, or solely specific software is required for the transformation process.
	Required assistance from non-target group individuals.	- Requesting the floorplans requires assistance, and depending on the software used (undoubtedly self-developed) assistance is required to operate it, when target group characteristics are not considered.	+ Depending on the software used (undoubtedly self-developed) assistance is required to operate it, when target group characteristics are not considered.
Target Group-specific Factors	Language, communication, and auditory reception	++* The software is not yet developed, requiring a development process for it to work. This factor will therefore be considered during the developed process.	++* The software is not yet developed, requiring a development process for it to work. This factor will therefore be considered during the developed process.
	Reasoning, working memory, and cognitive speed	++* The software is not yet developed, requiring a development process for it to work. This factor will therefore be considered during the developed process.	++* The software is not yet developed, requiring a development process for it to work. This factor will therefore be considered during the developed process.
	Memory and learning	++* The software is not yet developed, requiring a development process for it to work. This factor will therefore be considered during the developed process.	++* The software is not yet developed, requiring a development process for it to work. This factor will therefore be considered during the developed process.
	Visual perception abilities	++* The software is not yet developed, requiring a development process for it to work. This factor will therefore be considered during the developed process.	- The user is required to reproduce the specific of an indoor space, which is limited by their deficit in visual perception abilities. Additional assistance should be included to support this process.

Table 9: User experience -related factors of floorplan-based reconstruction methods.

* When the software is designed during this research.

Recommendations derived from strengths and weaknesses analysis.
Depending on the requirement of present assistance it could be argued that excluding commercially available image capturing, and 3D scanning equipment is favourable. Depending on the capabilities of a specific user, independently operating such equipment could be ill-advised, as issues during the capturing problems may arise that are not solvable for said user without aid. As an alternative, self-developed applications containing these capturing elements could be designed where all characteristics of MBID are considered in order to prove higher accessibility to those users; however, this still relies on the individual capabilities of an individual as they need to perform the capturing process alone. Although the domains presented by Wehmeyer et al., (2004) are applicable to generalised limitations in cognitive functioning, each individual with MBID is unique. Therefore, the design process should include a more thorough examination on how to address these unique features. Developing applications, focused on user-designed floorplans, can be considered favourable when the aforementioned design principles are considered and implemented. Overall, it seems that self-developing applications is the way to go to counter the external barriers and provide guidance in tackling limitations presented by internal barriers. Additionally, abstaining from using image capturing and 3D scanning equipment in indoor spaces limits the risks of drawbacks and the need for present assistance; instead, approaches that can be conducted everywhere without the need for assistance are recommended.

5.5 Requirement Specification and Validation

The previous section discussed the elicitation and analysis of the requirements; however, a prioritization process should be conducted in order to assess the importance of each requirement.

5.5.1 MoSCoW Prioritization

The MoSCoW Prioritization method will be used to assess the priority of the requirements (Clegg & Barker, 1994). This method is an often-used asset by designers and developers to acquire clear prioritization of a range of requirements or functionalities given the stakeholder's needs and time constraints. This method contains four groups, each indicating a level of implementation necessity:

- *Must-have:* Requirements presented in the *must-have* list are deemed critical to successfully acquire the desired result. These requirements are paramount for acquiring answers to the proposed research questions and the system is considered invalid when these requirements are not met.
- *Should-have:* Requirements presented in the *should-have* list are deemed important, but are not necessary to successfully acquire the desired result and answers to the research questions.

- *Could-have:* Requirements presented in the *could-have* list are deemed desirable, but are not necessary to implement at this current time. Although they can improve the user experience for little development cost, this might be done in later iterations if time and resources permit it.
- *Won't-have:* Requirements presented in the *won't-have* list are deemed as the least-critical and inappropriate at this time. These requirements are not considered in the current design process, but might be reincluded in later iterations.

5.5.2 Prioritized set of Requirements

The prioritized requirements can be found in the tables below. Table 10 contains the prioritized business requirements, Table 11 contains the prioritized user requirements, Table 12 contains the prioritized functional system requirements, and Table 13 contains the prioritized non-functional system requirements.

Each table contains the short term which encapsulates the identity of the requirement, a short description explaining the meaning of the requirement, and their determined priority level.

	#	Requirement	Description	Priority
Business requirements	1	Safety	the generated environment is reviewed as safe by the qualified Tactus treatment providers before the clients use it.	Must
	2	Data Privacy Compliance	the data of the users should be handled according to the AVG.	Must
	3	Medical Device Compliance	the application should take the MDR requirements into account	Must
	4	Development and maintenance cost	the costs of the development and maintenance of the final product should be within a to be determined budget.	Should
	5	Supplementary technology costs	the costs of the purchase of additional software and hardware to support the final product should be within a to be determined budget.	Should
	6	Portable accessibility	the final product should be capable of being easily setup in any room located in the organisation, which should limit the amount of hardware needed.	Should

Table 10: Prioritized business requirements of the proposed system.

	#	Requirement	Description	Priority
User requirements	7	Internal barriers	EU1 should be able to fluently interact with the system without being obstructed due to internal barriers.	Must
	8	Information acquisition	EU1 should be able to acquire/input the geometric and semantic information from an indoor space with relatively high accuracy.	Must
	9	VR immersion	EU1 should be able to view the reconstructed indoor space in VR.	Must
	10	Required assistance	EU2 should be able to help EU1 during the interaction with the system; however, should not participate in operating the system.	Should
	11	External barriers	EU1 should be able to fluently interact with the system without being obstructed due to external barriers.	Could

Table 11: Prioritized user requirements of the proposed system.

	#	Requirement	Description	Priority
Functional system requirements	12	Spatial dimensions	the system allows for the acquisition of the spatial dimensions of an indoor space with relatively high accuracy.	Must
	13	Fenestration position	the system allows for the acquisition of the position of the fenestration features of an indoor space with relatively high accuracy.	Must
	14	Furniture position	the system allows for the acquisition of the position of furniture located in an indoor space with relatively high accuracy.	Must
	15	Fenestration characteristics	the system allows for the acquisition of the characteristics of the fenestration features of an indoor space with relatively high accuracy.	Must
	16	Furniture characteristics	the system allows for the acquisition of the characteristics of furniture located in an indoor space with relatively high accuracy.	Must
	17	Tunneling	the system allows for directed guidance throughout the process.	Must
	18	Interior surface textures	the system allows for the acquisition of the interior surface textures of an indoor space with relatively high accuracy.	Should
	19	VR porting	the system allows for the 3D reconstruction of an indoor space to be ported to an HMD.	Should
	20	Generation process	the system allows for the generation of a 3D reconstruction of an indoor space using the acquire geometric and semantic information.	Could

Table 12: Prioritized functional system requirements of the proposed system.

	#	Requirement	Description	Priority
Non-functional system requirements	21	Language	the language used in the system should be in Dutch.	Must
	22	Protected storage	the reconstructed indoor spaces should be safely stored so that no private information can be shared in public.	Could

Table 13: Prioritized non-functional system requirements of the proposed system.

5.6 System Proposal

Previous analysis highlighted the range of possible methods the system could implement to be able to reconstruct AUD-related indoor spaces. The presented recommendations are focused on encapsulating their strengths and weaknesses in regard to accurate extraction of geometric and semantic information, as well as highlighting their level of potential user experience in regard to the target group. This resulted in the conclusion that methods related to user-designed floorplans in the form of a self-developed application are beneficial. The interpretation of such a self-developed application with user-designed elements is quite broad as numerous approaches can be deemed feasible. Discussion with experts in this field indicated that simply having users of the target group draw a floorplan from recollection is not advised, because of clear internal barriers obstructing this approach. After an individual brainstorm, the following system proposal was envisioned.

The proposed system aims to simplify the floorplan design process by using a directed guidance approach. This approach involves guiding the user through the design process step-by-step, using a dialogue-based interface on a touchscreen device. The goal is to help the user identify relevant AUD-related contextual features and use them to recreate their living room on a self-developed application. By guiding users through the process with text-based instructions, the system minimizes internal barriers such as deficits in reasoning, working memory, and cognitive speed. To achieve this, the system limits the number of choice options available to the user.

The system process is divided into five phases: *introduction*, *information acquisition*, *floorplan validation and storage*, *environment finalisation* and *VR immersion*.

Introduction: The treatment provider will introduce the goals and the process of the system before delving into the application. Minimizing confusion in advance is key when fluent interaction is desired.

Directed guided information acquisition: Once the goals and process of the system have been clarified and the user confirms their understanding of the system, the guided information acquisition process is initiated. In order to acquire the geometric and semantic information of the features located in an indoor space, a five-step information acquisition process should be conducted:

(1) *Feature elicitation:* Identify feature(s) located in the selected indoor space. The order in which features are indicated could be unique for every user. It depends on the steering of the narrative by the user and the treatment provider.
(2) *Semantic information acquisition:* Indicate the characteristics of said feature(s) by using the build in menus. The application has a build in procedure where specific characteristics of all features can be indicated (e.g., type, textures, colours, and shapes). The internal barriers of the users are addressed during the interaction with the menus.
(3) *Geometric information acquisition:* Indicate the position of said feature(s) by dragging the create 'node' to the desired position. The internal barriers of the users are addressed during the interaction with the floorplan.
(4) *Feature validation:* A switch is included where users can view the 2D floorplan in 3D to verify the input. Providing a 3D point-of-view addresses the users' deficits in visual perception abilities.
(5) *Floorplan validation and storage:* Once the complete floorplan has been constructed, the users will once again validate the accuracy of the input. Once the users are content with the results, the environment will be stored for later use.

Environment finalisation: In order to immerse users in their reconstructed indoor space, additional features should be included into the environment (e.g., VR interaction framework, atmospheric features).

VR immersion: Finally, the users can be immersed into their self-designed indoor space.

Chapter 6. System Design

The previous chapter presented a set of relevant requirements for the system that will be constructed for this research. This chapter highlights the implementation of these requirements during the development of a system. The system aims to present VR environments of personalised reconstructed indoor spaces based on acquired geometric and semantic information from users of the target group. The 'must-have' and 'should-have' requirements are grouped into four main functions: *Acquisition of Geometric Information, Acquisition of Semantic Information*, *Directed Guidance Process*, and *VR Immersion*. The implementation of these functions is discussed in the sections below as well as their relevance to addressing the internal barriers of the target group.

Based on the system proposal of the previous section, a system capable of reconstructing indoor spaces through the acquisition and translation of geometric and semantic information was developed. The focus is on user experience to the defined target group. Figure 2 displays the basic functional structure of the developed system KamerMaker with regards to information acquisition.

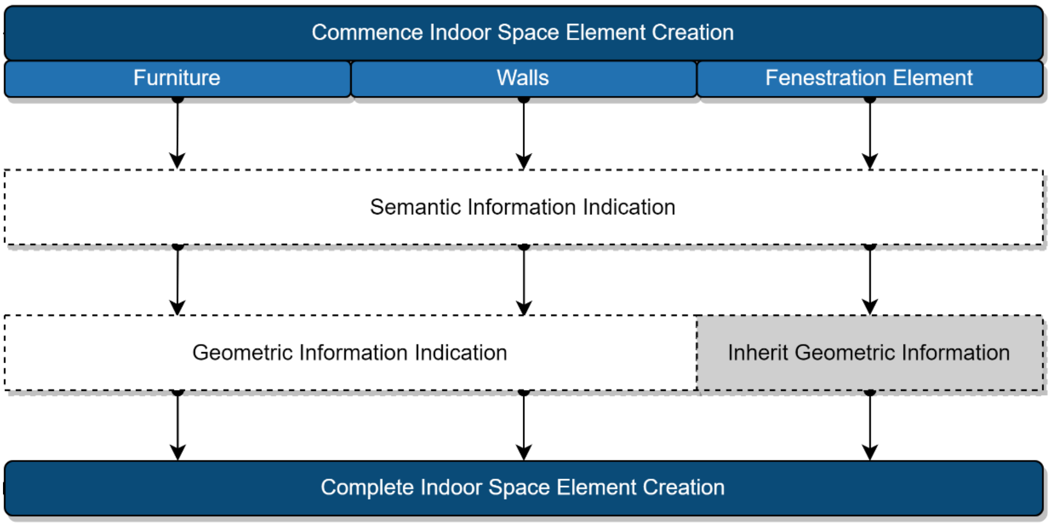


Figure 2: Basic functional structure of the developed system.

The first step in the proposed system involves allowing the user to select the type of indoor space element (ISE) they want to construct. The system offers four different ISE types: furniture, walls, fenestration elements, and floors and a ceiling. The user can manually include furniture, walls, and fenestration elements into the environment, while the floors and ceiling will be generated automatically in the final process. The following sections describe the process of acquiring semantic and geometric information from the user, as well as how the dialogue-guided process and VR have been integrated into the KamerMaker system.

6.1 Acquisition of Semantic Information

Related requirements: 7, 9, 15, 16, 17

There are various approaches to acquiring the semantic information of an ISE; however, as discussed in Chapter 5.4.1, factors related to the approach's accuracy and user experience should be considered. The *accuracy-related factors* highlight the extent to which the reconstruction methods are capable of extracting accurate geometric and semantic information from indoor spaces, and *user experience-related factors* highlight the usability and quality of user experience of the reconstruction methods in relation to the stakeholders.

Two approaches have been thought up: *linear characteristic indication*, which relies on the users' free recall memory abilities, and *indication though resemblance* which relies on the users' recognition abilities.

With the *linear characteristic indication* approach, the user is presented with a series of menus in which each specific characteristic of an ISE is indicated. Figure 3 displays a flow diagram of an example prototype menu series for recreating a couch model with high accuracy. Each ISE type would require its own unique sequence of menus in order to address each of their unique characteristics.

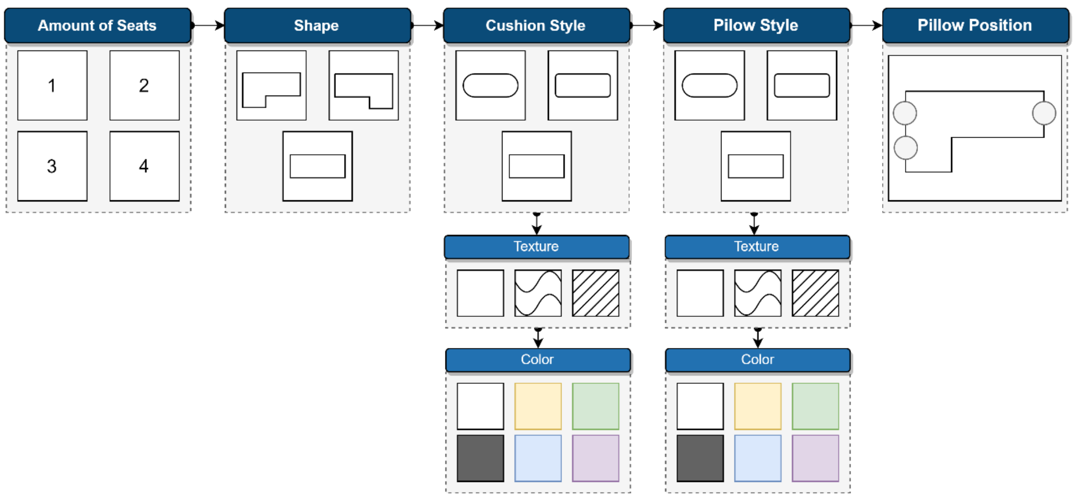


Figure 3: Step-by-step characteristic indication process.

On the other hand, *indication through resemblance* presents the user with a short series of menus in which initially the colour of the ISE is indicated, followed by a menu containing a set of carefully selected 3D models. The user is required to browse through the pre-determined set of 3D models of the selected ISE in order to find a model that resembles the ISE at home. The 3D models included in the system cover a large range of styles of an ISE in order to increase the probability of an accurate match. Figure 4a displays the menu series of this approach for furniture and fenestration elements, and Figure displays the menu series of this approach for walls, floors, and ceilings.

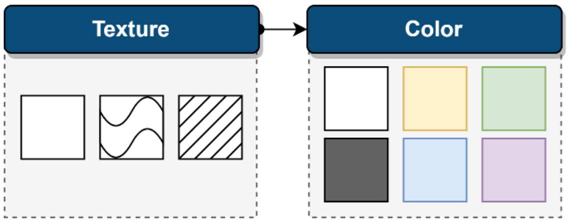


Figure 4a: Indication through resemblance process for walls, floors, and ceiling elements.

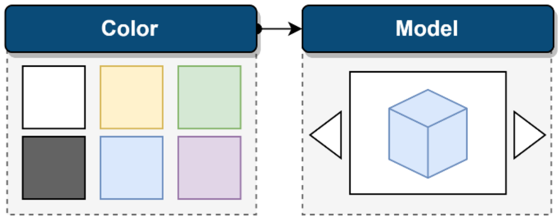


Figure 4b: Indication through resemblance process for furniture and fenestration elements.

The system will implement the *indication through resemblance* approach to acquire semantic information as recognition memory requires less effort than free recall memory (Raaijmakers & Shiffrin, 1992). It should be noted that Lifshitz et al., (2011) found that people with an intellectual disability *"exhibit difficulties in recall as well as in recognition"* (p.106); however, the choice was made to implement the approach which requires the least amount of cognitive effort. The selected approach also requires less dependence on the ability of sequential reasoning than when recreating the ISE step-by-step.

Prior to the indication through resemblance approach, the current iteration of the KamerMaker system has the user select the desired type of furniture. Figure 5 shows the current menu where the user performs this selection.

Figure 5: Furniture type selection menu in the KamerMaker system.

When a furniture type has been selected, a new menu is displayed where the user can indicate the colour of the furniture. The screen consists out of 21 coloured button the user can press to select. The decision was made to have the user select the colour of the furniture prior to selecting the actual model of the furniture. This is because we felt it would be more difficult for the users to find resemblance into furniture models that are not of the desired colour. Once the user has selected the colour of the furniture type, a new menu is displayed containing a single furniture model of the selected furniture type. The user can now browse through the different models by using the buttons on the side, and select a model by pressing the button underneath the model (see Figure 6).

Figure 6: Furniture model selection menu in the KamerMaker system.

The same approach is implemented during the semantic information acquisition of walls and fenestration elements; however, the initial type of selection menu is redundant and is therefore not included.

6.2 Acquisition of Geometric Information

Related requirements: 7, 8, 12, 13, 14

After the user has indicated the desired semantic information of an ISE, the geometric information will be acquired. Each ISE type has a distinctive approach to acquiring this information with regards to the way the interaction is performed, and when the interaction is performed. The following sections will describe the approach to geometric information acquisition of furniture, walls, fenestration elements, and floors and ceilings, respectively.

6.2.1 Furniture objects.

After having concluded the semantic information acquisition process for furniture objects, a 3D model of the created furniture object will spawn in the middle of the current view of the environment. The user can perform two interactions on the touchscreen device to position the ISE accurately: *drag* an object to transform the position, or *double tap* on the ISE to transform its rotation by a pre-determined number of degrees. These actions can only be performed when the user has selected the objects beforehand by pressing on it once. The user will see when an object is selected as a white outline will appear around said object (see Figure 7). To deselect an object the user can press on another object, another ISE element, or the grid/floor of the top-down view of the environment.

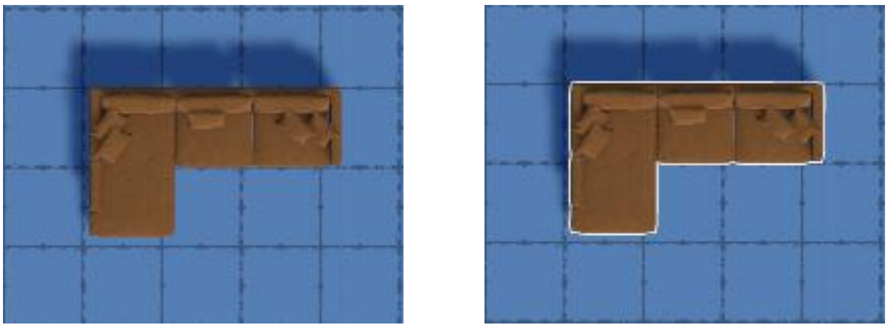


Figure 7: An unselected and selected furniture object in the KamerMaker system.

6.2.2 Walls.

Two approaches to wall placement have been thought-up: *dynamic wall placement*, where the user can drag his finger over the screen and place individual walls between grid intersections (see Figure 8a for an example of its functionality), and *paired wall placement*, where the user presses on two separate intersections on the grid and a wall will be instantiated between these points (see Figure 8b for an example of its functionality). Each approach has its benefits and drawbacks.

The *dynamic wall placement* approach is a more intuitive-based interaction where walls are placed on the position of the user's touch. However, this does make the approach more prone to errors as it is easy to drag the finger to unintended positions on the touchscreen. This approach is also only capable of placing walls in three directions (i.e., horizontal, vertical, and 45°), which limits the creative freedom and possibilities during the reconstruction process.

The *paired wall placement* approach is a less intuitive interaction, but is still relatively simple to understand and perform. This approach is significantly less prone to errors as users have to confirm the correct placement of walls. After the user has selected the first point on the top-down grid the second position can always be changed until the user is happy with how it looks. Confirming the position will instantiate the actual wall elements. This approach, although more difficult to develop, can create walls with every desired angle and does not limit the creative freedom and possibilities during the reconstruction process.

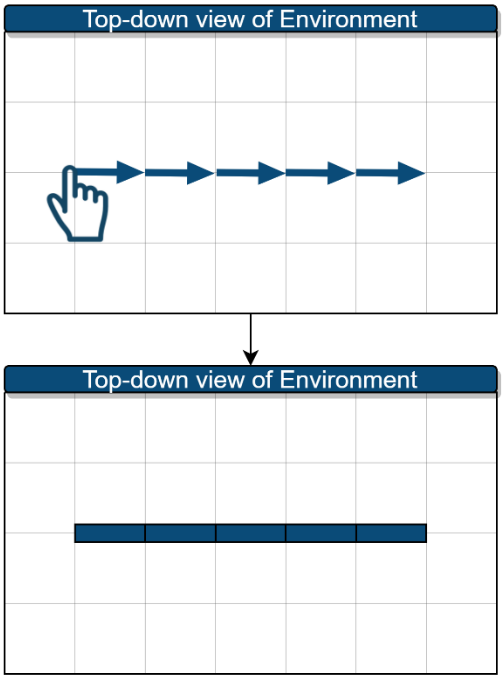


Figure 8a: Example of dynamic wall placement.

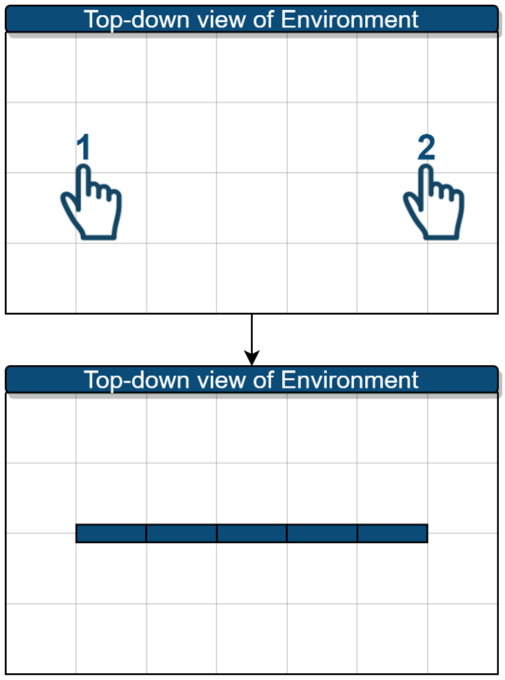


Figure 8b: Example of paired wall placement.

Discussions with stakeholder resulted in the implementation of the latter approach, because of its broader range of possibilities. We want to prevent that users of the target group cannot reconstruct a specifically positioned wall in their living room, which could result in unnecessary confusion and less accurate reconstructions of their living rooms. It should be noted that a tutorial should be included where the user can clearly see and practice the mechanics of this approach.

The KamerMaker system requires the user to press a button in the options menu to let the system know the user is going to build a wall (see Figure 9). Then the user can press two points on the grid to build a wall between these two points. The system automatically deactivates the build mode and requires the user to once again press the indicated button to start building. This is done to prevent users from accidentally creating walls.

Figure 9: Wall creation process in the KamerMaker system.

6.2.3 Fenestration elements.

In order to place a fenestration element in the environment, the user must have created a wall beforehand. The geometric information of fenestration elements is inherited from its indicated source; meaning that the user can select one, in case of a door, or multiple walls, in case of windows, on which the fenestration elements will be created. All necessary geometric information is already present in the wall elements, which will be passed on.

6.2.4 Floors and ceilings.

Unlike the other ISE types, floors and ceilings are instantiated at the final step of the system, where solely semantic information is required. The floor and ceiling elements are divided into planes with the dimensions of the grid. An algorithm will place these planes between the previously instantiated wall elements (see Figure 10 for an example of its generation process). However, this is only possible after a check confirms that the reconstructed indoor space is enclosed with walls.

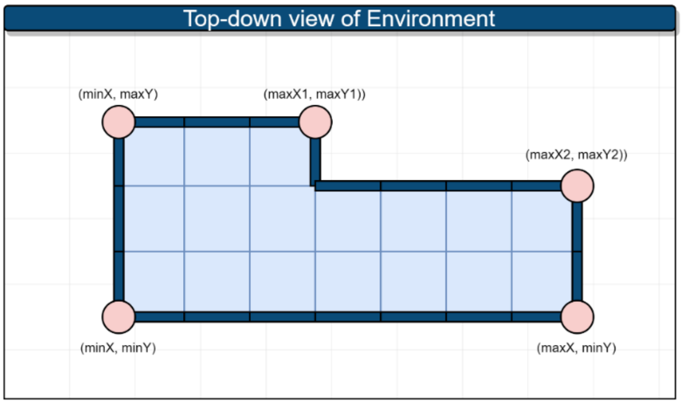


Figure 10: Example of floor and ceiling generation

6.3 Directed Guidance

Related requirements: 7, 9, 17, 21

The system was designed with the requirement that staff of Tactus Verslavingszorg should be able to assist individuals of the target group during their interaction with the system, but should not be involved in operating the system, only providing help when necessary. To support the main users of the system, a step-by-step process with specific dialogue was created to guide the user throughout their interaction. This step-by-step process of directed guidance, also known as a "tunnelling" process in the context of persuasive technologies, supports users' sequential reasoning and acts as a memory assistance tool during their interaction with the system. By providing a limited number of options at each step, the system reduces the cognitive load on the user and makes it easier for them to understand and follow the process. Clear, concise instructions are provided at each step, helping users understand what they need to do next and reducing the risk of confusion or frustration. Additionally, breaking down the task into smaller, manageable steps, the system helps users to focus on one thing at a time, reducing the cognitive load and making it easier to recall what they have done before. This will be especially helpful for users with intellectual disabilities, as it will help them to understand what to do next, reduce the risk of confusion or frustration, and make it easier for them to recall what they have done before which will help them to complete the task efficiently.

The proposed application is structured with menus and states to track the user's progress. This system provides specific text-based guidance and support during specific tasks. To allow the user to progress at their own pace, there are no time-gated actions included in the design. Instead, the user navigates through the dialogue by manually pressing the 'next' or 'previous' button (see Figure 11). In order to fulfil requirement 19, the language used is in Dutch and has been written in A2 level.

When the texts refer to a specific button that the user must press to continue, two separate guidance elements will be on display. An image of the referenced button is presented within the text including a clear description of the location of this button. As seen in Figure 11 the image of the button is shown together with the text *"Press the button […] at the bottom of the screen to create new furniture."*.

Figure 11: Dialogue displayed in the KamerMaker application.

When closed questions are presented to the user in order to make progress, the user is presented with 'yes' and 'no' buttons (see Figure 12: Closed questions presented in the KamerMaker application.). These act as an additional step to guide the users step-by-step through the process. This approach limits the number of options available to the user at any given time and makes it easier for them to understand and follow the process. Additionally, both buttons are also repeated again in the text to make them clearer and more prominent. This will help users to understand what to do next, reduce the risk of confusion or frustration, and make it easier for them to recall what they have done before which will help them to complete the task efficiently. The use of closed question in the system will also provide a way to validate the user's decision, by giving them the choice to indicate their agreement or disagreement with a certain statement.

Figure 12: Closed questions presented in the KamerMaker application.

The design of the buttons in the KamerMaker application has been carefully considered to reduce the users' cognitive load and improve their understanding of the text. The recommendations of Dekelver et al., (2015) have been considered in the design and implementation of the tunnelling system. To help users understand the text on these buttons better, related images are placed adjacent to the text. This visual cue helps users to understand the context and the function of the button. The language used is plain and in a brief and concise form, making it easy to understand. High contrast colours are also used to make the buttons stand out and be easily recognizable. Additionally, the placement and size of the buttons are also designed to be intuitive, and to make it easy for the user to find and press them. The use of clear and simple iconography, or visual representation of the button's function, will also help users with intellectual disabilities or low digital literacy to understand the button's function.

The image points to the precise location of the button, providing a visual cue for quick identification. The image is highlighted in the text to draw the user's attention, making it easier for those with visual impairments or low digital literacy to understand the button's function. This approach aims to improve the user's engagement and interaction with the system, but also tries to make it more personalized and interactive. Additionally, it aims to help users with cognitive impairments to locate buttons with ease, reducing confusion.

Figure 13: Button indication animation frames in the KamerMaker application.

6.4 VR Immersion

Related requirements: 1, 7, 9, 19

A Virtual Reality HMD is permanently connected to the computer to offer the users the option to view their progress and end-result in first person. During the reconstruction process users might need to get visual feedback on their progress to verify that their current progress does resemble their living room. Therefor a button is implemented so that users can place a camera into the environment on which a VR camera component is attached. When putting on the VR HMD, specific Oculus functionalities have been altered to ensure a smooth transition to viewing the virtual environment without additional requirements. In order to address the requirement regarding the safety of the users, a Guardian (i.e., a built-in safety feature that lets you set up boundaries in VR that appear when you get too close to the edge of your play area) is set-up to ensure the users will not walk out of a pre-determined safe zone.

The goal of the KamerMaker application is to provide clients with the opportunity to get VR-Therapy in reconstructed environments resembling familiar environments. Therefore, the addition of VR immersion is fundamental during the development of such environments to ensure quality during these therapy sessions.

6.5 Discussion

This chapter discussed the design of a system in which users can reconstruct their living rooms within a virtual environment using a dialogue-guided step-by-step process. The application was designed and developed in accordance with the specified requirements set in Chapter 5.5.2. As this study is focussed on a specific target group that requires unique approaches to find a solution to the proposed research problem, many different realization approaches could be found viable. KamerMaker will be evaluated to identify if it is one of these viable solutions and provide an answer to RQ2: *How can indoor spaces be reconstructed using personalised contextual information acquired from individuals with MBID?*

The goal of this chapter was to describe the functionality of the KamerMaker system and emphasize the relation between the design choices and the specified requirements. All must-have functional- and non-functional system requirements have been implemented into the system and described as separate functions in each section. Of the must-have user requirements, information acquisition is implemented into Chapter 6.1 and Chapter 6.2, and VR immersion is implemented into Chapter 6.4. Addressing the internal barriers of the target group into the design choices is the only must-have user requirement that stretches across all functions. Many considerations and trade-offs between accuracy and user experience have been made aiming to optimize the user experience and accessibility of the system.

Chapter 7. Evaluation

The previous chapters discussed and answered the first two research questions posed in Chapter 1.3. These answers provided context and direction for a suitable design which should be evaluated respecting usability and user experience. These aspects are formulated into two research questions.

> RQ3: *How do the users of the target group experience the geometric and semantic information extraction?*

> RQ4: *How do the users of the target group experience the reconstructed personalised immersive virtual environment?*

RQ3 is twofold: (1) it focusses on identifying if this type of system is a suitable approach to the presented research problem, (2) it focusses on identifying how users experience the KamerMaker system specifically in terms of usability and user experience. RQ4 is related to how the users experience the reconstructed living room in VR.

7.1 Method

7.1.1 Research Design

We conducted a usability test to evaluate the user experience and usability of the KamerMaker system described in the previous section. In doing so, we also aimed to assess the feasibility of this approach in allowing individuals of the target group to create a virtual reconstruction of an indoor space.

7.1.2 Participants

The participants of the evaluation study consisted out of five individuals (i.e., P1 through P5 for brevity) who have mild intellectual disability (IQ = 50-69) or borderline intellectual functioning (IQ = 70-85). The sample comprised of two female participants and three male participants with mean age of 31 (SD = 5.1, min=23, max = 38). Aveleijn, a healthcare organization for children, youth, adults and seniors with intellectual disabilities and low social functioning, connected us with the participants.

Participant	Gender	Age	VR experience
P1	M	32	No
P2	M	34	No
P3	F	38	No
P4	F	30	No
P5	M	23	Yes

Table 15: Participant's information.

Participants were screened beforehand by coworkers of Aveleijn and filtered on their risk to adverse effects related to the experiment. Inclusion criteria were diagnosed mild intellectual disability or borderline intellectual functioning and a minimum age of 18. Exclusion criteria involve the presence of epileptic tendencies as VR can evoke seizures in people with epilepsy. Additional criteria are disruptive motor impairments, obstructive visual impairments, and severe mental disorders (e.g., schizophrenia, psychosis). Furthermore, a minority of participants can experience cybersickness whilst being immersed into VR applications or become anxious during the research procedure. Both issues will be addressed before the immersion by carefully explaining the possibility to these effects. In case the participant does not feel comfortable, the experiment will directly be paused/stopped by carefully removing the HMD from the participant's head.

7.1.3 Hardware and IVE

The experimental setup consists out of an ACER 23" touchscreen monitor, Oculus Quest 2 HMD, and a PC powering them both and running the KamerMaker software. The setup of the experiment is divided into two sections: (1) the researcher's setup, which can be seen in Figure 17a: Researcher's view of the setup. A PC can be seen which runs KamerMaker application. The screen shows the researcher the view of the VR HMD.; (2) the participants setup which can be seen in Figure 17b: Participant's view of the setup. The touchscreen in front of the participant runs the KamerMaker application. The VR HMD can be worn to view the virtual environment.. Additionally, a smartphone was used to capture audio during the experiment. The smartphone

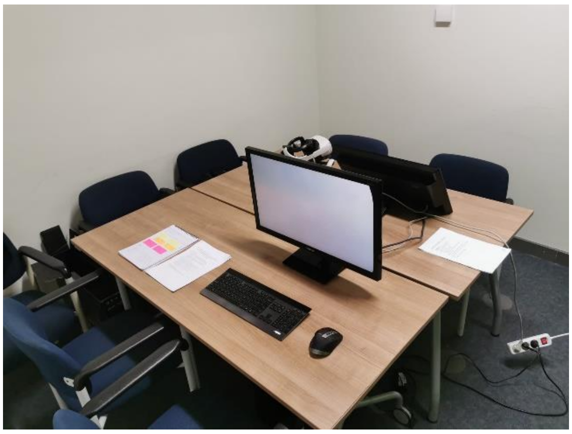


Figure 17a: Researcher's view of the setup. A PC can be seen which runs KamerMaker application. The screen shows the researcher the view of the VR HMD.

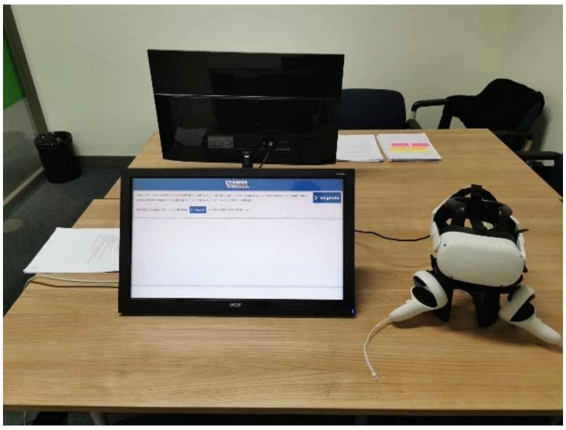


Figure 17b: Participant's view of the setup. The touchscreen in front of the participant runs the KamerMaker application. The VR HMD can be worn to view the virtual environment.

was placed in close proximity to the participant, and the audio recording was synced with the video recording captured by the KamerMaker software. This allowed for a comprehensive analysis of both the visual and auditory aspects of the experiment.

7.1.4 Measures

The usability test involved a combination of two data collection techniques to gather information on user experience and usability: (1) semi-structured interviews with audio recordings, and (2) behavioural observations through screen recordings and think-aloud audio recordings. In total six short semi-structured interviews were conducted after six of the seven segments: (1) directed guidance, (2) furniture-creation and manipulation, (3) fenestration creation and manipulation together with tutorial reflection, (4) mid-interaction VR immersion, (5) full KamerMaker functionality, and (6) full VR immersion. During each interview, the focus was on exploring the participants' experiences and identifying any usability issues they encountered. The questions of the full VR immersion were based on the Igroup Presence Questionnaire (IPQ, Schubert et al., 2001). As one of the most commonly used measurement method for measuring the in Chapter 5.3.2 discussed phenomenon of presence (i.e., the subjective experience of being in one place or environment, even when one is physically present in another, Witmer & Singer, 1998) are questionnaires (Mai, 2018). However, because of the characteristics of the target group, a semi-structured interview which implemented the factors of the Igroup Presence Questionnaire was conducted. By adapting the IPQ for a semi-structured interview format, we can ask questions based on the IPQ's factors, get more detailed information into participants' experiences, and gain a more nuanced understanding of their feelings of presence in the virtual environment. This 14-item questionnaire assesses 'presence' based on 4 subscales: (1) general presence, (2) spatial presence, (3) involvement, and (4) experience realism. In order to enhance the suitability of our study for our target group, we have refined the 14-item IPQ questionnaire by selecting one representative question from each sub-scale. This adaptation aims to reduce the cognitive burden on participants while maintaining the questionnaire's reliability and validity. Our focus is on specific aspects of the original questionnaire, and we have rephrased the questions in a more target-group appropriate manner to facilitate participant engagement. An overview of all questions asked during the interviews can be found in Appendix F: Experiment Procedure and Interview Questions.

The thinking aloud method was employed during the usability test to capture the reactions of participants and to gather insight into the participants' decision-making processes, as well as to identify any difficulties they may have encountered while using the system. This method involves asking the participant to verbally express their thoughts and actions while they perform a task within the system. Screen recordings of the user's interaction with the KamerMaker system were captured to provide a visual representation of the user's experience. These recordings were used to reflect on the usability issues that arose during the test, as they allowed us to observe the user's actions and identify any challenges they encountered while using the system. The screen recordings are used in conjunction with the other data collection techniques, to provide a more complete insight into the participants' experience.

7.1.5 Procedure

The participants were greeted and provided with an introduction to the study, including a detailed explanation of the research objectives and a review of the study brochure. Once the participant had complete knowledge of the study and agreed with the terms, an informed consent form was signed to comply with the ethical principles set by the University of Twente and the Declaration of Helsinki. The brochure and consent form can be read in **Appendix E: Study Brochure and Informed Consent Form**. The technology used in the research was explained by introducing and explaining the touchscreen and the VR HMD.

When the participants indicated that they were ready to start with the experiment, the audio- and screen recordings were started. To guarantee the precision of the data collected, each experiment had a maximum duration of 60 minutes. This time limit has been carefully chosen to accommodate the specific needs of our target group, such as attention span and perseverance. By implementing this approach, we can ensure that the experimental conditions are optimized for our participants, ultimately leading to more accurate and reliable results. The experiment consisted of multiple segments that the user must interact with and provide answers for after which the semi-structured interviews were conducted. The contents of the segmented structure can be seen in **Figure 18:** Segmented structure of the experiment design..

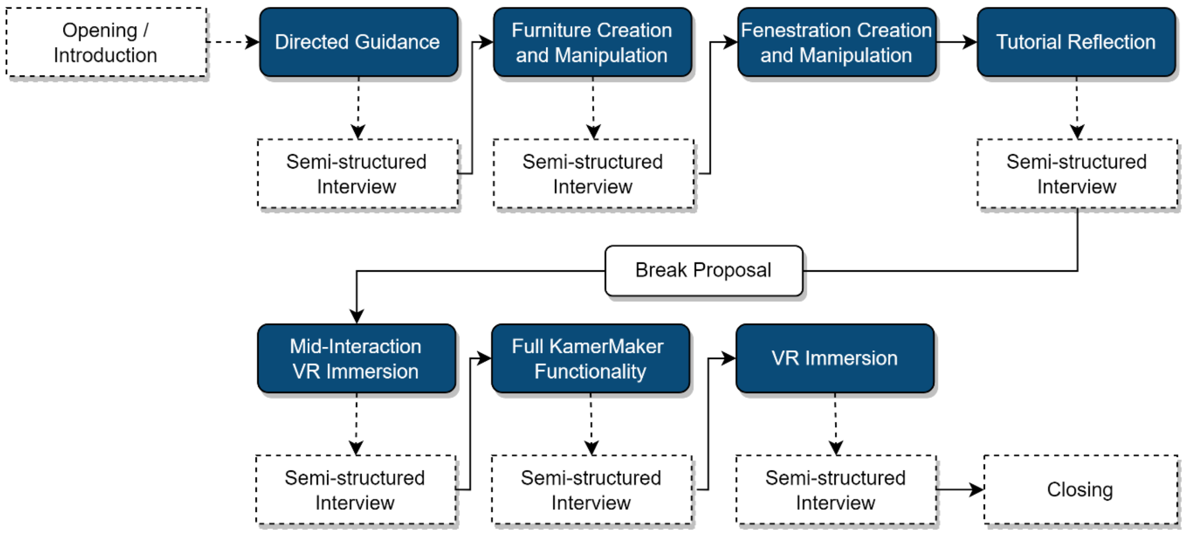


Figure 18: Segmented structure of the experiment design.

Each segment contained its own set of unique tasks that the participant had to complete in order to continue. They were asked to follow the instructions given in text form as part of a directed guidance through the application. During the interaction, the participant's progress was only paused when it is clear that the participant was stuck and clearly indicated that they don't know how to continue. The participant was then asked what part of the instructions were unclear and how they think it could be improved. Once a participant had fully completed a segment, they were notified to stop with the interaction and answer questions in the form of the segment-related semi-structured interview. This process was repeated up until the mid-interaction VR immersion segment, as participants were asked if they want to take a break to reduce the cognitive load.

Before beginning the VR immersion experiment, participants were once again reminded of the potential adverse effects that may occur during the experience. Once they signaled their readiness, the VR immersion commenced. After the completion of the experiment, a debriefing session was be held with the participants to address any lingering questions or concerns they could have had. This was an opportunity for the participants to express their thoughts and feelings about the experiment. Once all questions and concerns had been addressed, the participants were thanked for their participation and the audio- and screen recordings were stopped and securely stored.

7.1.6 Thematic Analysis

To answer the research questions of the presented study, the qualitative data was analysed by conducting a thematic analysis approach as discussed by Braun & Clarke, (2006). The purpose of this thematic analysis is to identify, analyse, and find patterns in regarding the experiences of targeted users who use the KamerMaker software. This process included six phases: (1) familiarizing yourself with your data, (2) generating initial codes, (3) searching for themes, (4) reviewing the themes, (5) defining and naming themes, and (6) producing the report. The audio recordings of the semi-structured interviews were transcribed verbatim as well as the audio recordings of the think aloud method. We used the qualitative data analysis program ATLAS.ti 23 for conducting the analysis.

During the familiarization of the data, the interviews have been listened to again, and the transcripts have been re-read. In the next part the data was organised in a meaningful and systematic way by adding codes to the corpus. This reduced the amount of data into smaller, meaningful segments. An inductive coding approach was applied, which means that themes emerge naturally from the data, without any preconceived notions or expectations. The process is data-driven, and the analysis focuses on identifying patterns and themes that are genuinely present in the data. Themes in this sense are considered a pattern that identifies an interesting aspect of the data and/or research question.

7.2 Results

From the initial phase of familiarizing myself with the data, through generating initial codes, searching for themes, and reviewing these themes, the goal is to generate a detailed understanding of the participants' experiences. This led us to defining overarching themes that capture the essence of the user experiences and usability of the system. In this section, the themes and sub-themes that resulted from this analysis will be discussed, in which the target group’s experience of both the geometric and semantic information extraction process and the reconstructed personalised immersive virtual environment will be highlight. The analysis resulted in the following themes and sub-themes:

- *Need for Clear Content:* This theme focuses on how the UI design is deemed effective for users and how task examples and required information are presented logically and accessibly for the target group.
- *Interaction Barriers:* This theme highlights how participants got stuck during the interaction and which interaction mechanics seem to be difficult to handle for the participants.
    - *User-specific Interaction Barriers:* This subtheme highlights occurrences where user-specific barriers resulted into a halt of the interaction. (Example codes: user has perfectionism, autism requires user to have everything perfect, request for quicker progression, more types of interaction approaches)
    - *Application Design-related Interaction Barriers:* This subtheme highlights occurrences where specific application design choices resulted in barriers in the interaction. (Example codes: technical limitations of the system, lack of guidance on interaction process, unclear rotation mechanics, wall creation mechanic unclear)
- *How Virtual Environments are Experienced:* This theme highlights the experiences of the users when they were being immersed into virtual reality to view their created environment.
- *Learning and Skill Acquisition:* This theme was extracted as there were several occurrences where remarks on the included tutorials were made and how practice seem to have an impact on the interaction process.

With the review of the themes completed, we now defined our main themes by identifying *"the 'essence' of what each theme is about."* (Braun & Clarke, 2006, p.92). The following sections will be discussing these themes.

7.2.1 Need for Clear Content

All participants found the implementation and presentation of the navigation and dialogue in the system to be logical and easy to follow. P2 stated that "*the information is good, and clearly explained"* followed by "*It's clearly indicated when I have to press something and when not*". They understood how the navigation buttons worked and reported no difficulties in using the system. Additionally, the inclusion of button images in the text was largely appreciated by the participants. For example, P1 said *"Imagine if I couldn't read, I would still be able to know what the icons mean"* and P4 indicated that *"It's clear to read, for example, if someone can't see properly, they would still be able to read it"*.

Some participants found the animation of a hand indicating where to press on the screen to be *"Nice*" (P4) and making it so "it makes it clear where to click" (P5). Another participant found it to be rather distracting, as it tempted users to immediately click the indicated button without fully reading the instruction dialogue. This resulted in the participant not fully reading the instructions and thus limit their understanding of the explained mechanics, which can impact their ability to effectively use the system. When asked about, the participant (P3) said that *"I see that hand on the screen and I was told that I should press there, so that's what I did"*. Additionally, this participant indicated that *"I find it annoying*. […] *If it was shown once it would have been okay, but it is shown constantly"*.

One participant (P5) found the "duplicate" button, which is not explained in the system as it was not deemed too important. This button was a great example of intuitive design as the participant stated that its functionality was simple to understand and logically implemented. The other participants did not find this button and therefore did not use its functionality.

7.2.2 Interaction Barriers

Application Design-related Interaction Barriers

This subtheme focuses on interaction barriers that were not specific to any individual user but were found to be challenging by most of the participants. These barriers are related to specific design choices made during the development of the application and can be categorized as application design barriers.

One of the major barriers found by most users was the manipulation of furniture models, where users are required to move and rotate created furniture objects. Four participants (P1, P2, P3, and P4) had difficulty with moving the furniture around the environment. It was generally unclear that the furniture model should be pressed first in order to select it before moving it, which caused confusion and irritation among the participants. All participants did not remember the requirement for selecting a specific object to move, and immediately started dragging their finger over the screen. One participant said that "*Well I don't like it when I have to do this*" (P2), referring to dragging their finger over the screen, *"I'd rather do it with a mouse"*.

Three participants (P1, P3, P4) had difficulties with rotating the furniture objects, which caused additional confusion and irritation. An interesting finding is that these participants all automatically tried to rotate the furniture model using the same interaction motion, which is similar to rotating the map in Google Maps. This motion can be called "pinch rotation" or "two-finger rotation" and describes the gesture where you place two fingers on the screen and move them in a circular motion to rotate the view of the map. This was provided as an example by a user, indicating that this interaction motion may be a common expectation among users when attempting to rotate objects in a digital environment. This was not the only time a reference was made to existing mechanics, as P1 also stated the following on placing walls into the environment: *"Yeah, you know, it sounds really strange, but if you did this in Sims, then you did it like this. Because when you built a house, you dragged the wall to the point where you wanted it. That's why it's a bit ingrained in my system, so to speak"*. This mechanic was repeated by P5 who stated that he would rather *"indicate a starting point in the environment, and then from there drag it to a specific location"*.

The indication of geometric information of the walls and fenestration objects generally appeared difficult as the majority of participants had difficulties when it came to placing the walls and fenestration objects in the virtual environment. Three participants (P1, P2, and P4) encountered difficulty in grasping the mechanics of the task. Interestingly, it's worth highlighting those two of these three participants (P2 and P4) overlooked the explanations provided in the dialogue and advanced through the menus hastily, leading to difficulties. When asked for alternative approaches for placing walls within the environment, all participants said that dragging the walls would be more logical, aligning with the proposed dynamic wall placement approach discussed in Chapter 6.2. After being shown how the mechanic works, only P1 understood it correctly and was able to use it. Two participants (P3 and P5) did find the geometrical indication logical and understandable, although P3 consistently made walls that were only one segment long, rather than placing the whole wall at once.

Another interaction barrier related to how the system was design relates to the possibility to create non-living room elements. As living rooms can be quite unique (e.g., P5 lives in an old monastery and had to recreate his parents living room) it became noticeable that not having the option to recreate every aspect of a room is a major downside. For example, most participants (P2-P5) stated that a kitchen should be added to the environment to make it more realistic. This hinders distance estimation as P5 indicated that his approach to placing the walls within the environment was based on envisioning aspects like an open kitchen and the stairs and then trying to guess the distance. Other missing elements that would make a living room more realistic would be a television (P2-P4), clock (P4), painting (P4), stairs (P5), glass doors (P1, P5), radiator (P5), specific plants (P1, P5) and a rug (P5).

User-specific Interaction Barriers

It became apparent that KamerMaker should not only address the generalized cognitive limitations of the target group but should also consider the co-occurrence of other limitations or comorbidities. Additionally, each individual can have specific preferences about how a specific interaction should work. One example is the presence of autism in users as P5 explained that: *"I have autism, so I want everything to be exactly right. This is not possible in such a virtual environment, so I had to select something that was close."* when talking about his opinion on the furniture selection aspect of the system. Upon asking how this influences his perception on the virtual environment in regard to recognizing the environment as his own living room, he explains that this will definitely have a big influence. The participant suggested a method for creating furniture, specifically a couch. *"A couch consists of components. As you can see here this model consists of three components. I can imagine that you could add another component in between the existing ones."* (P5). This suggestion aligns with the proposed step-by-step characteristic indication approach outlined in

Chapter 6.1, which suggests that more personalized furniture can be created when offering users the ability to customize and modify the models themselves.

Although considered, it seemed that the amount of text in the system was also excessive and unclear at some points for some users. Two participants indicated that the inclusion of audio fragments of the written text would be beneficial to support users that have more difficulty with reading. P5 stated: *"Yes, I would appreciate it if it is also read aloud, because in therapy you can be quite overstimulated and then you can absorb more information.* […] *I'm not exactly sure how it works, but I notice that I can remember information better when someone else reads it out loud. In the past, when I was still attending a different school, my teacher or parents helped me by reading the information aloud and I followed along"*. P2 also stated *"that having a voice speak that text would be useful"*.

The participants were also divided on the approach of selecting furniture. Generally, this approach was found to be effective and intuitive, however, a few participants (P3, P4, P5) indicated that the addition of more models could be beneficial for higher accuracy as *"their exact model was not present"* (P4). This is consistent with previous findings that suggest that a greater variety of options can improve the user experience and make it easier for users to find a model that meets their vision. P1 on the other hand proclaimed that "*for me it's good enough if the furniture looks a little bit like it. I don't mind that it is not the exact model*", and also mentioned that additional stress could be invoked when there is too much choice. However, it also showed that other participants (P3, P4, P5) indicated that the addition of more models could be beneficial for higher accuracy as their exact model was not present. P4 expressed that it was challenging to make the recreated living room look exactly like their own home, but that sometimes a piece of furniture was found that did remind her of the model she had a home: *"The table does not look like this, and also not like this. But it does look a bit like this!"*.

Differences in character also became apparent when both P1 and P2 skipped through the instructions of a task. P1 indicated that was in his nature, and wanted to go to practical handling instead of the presented theoretical approach of the instructions: *"It was quite clear, some things simply speak for themselves, and I am someone who is then quickly inclined to test it out in practice"*. P2 appeared to have difficulty understanding the instructions when reading them, and eventually became uninterested. However, when given complete control of the KamerMaker application to recreate their living room, P2 began to carefully read and follow the instructions again. Unfortunately, P2 became distracted by the prospect of adding furniture to the space, and their focus shifted away from the instructions. P2 suggested that including audio of the text could prevent this behaviour. They reasoned that people tend to keep listening before continuing the interaction, which could improve their understanding of the instructions and ultimately enhance the accuracy of their mental model.

7.2.3 Learning and Skill Acquisition

During the analysis of the study, another key component of the design that emerged as important was the role of learning how to use the mechanics of the application and how the process on how users acquire these skills. This was evidenced by several participants who demonstrated improved understanding through repeatedly performing tasks during their interaction with the system. P1, P4, and P5 showed more positive engagement with the system when they knew exactly how to tackle the task at hand. For example, one participant (P1), made a remark during the think-aloud process: *"I'm getting skilled at this"* while creating a new furniture model during the recreation. This participant's enthusiasm and confidence following this remark demonstrated the positive effects of understanding the mechanics of the application and knowing the exact interactions required to accomplish a task. When asked about it later, the participant stated: *"It takes some time to figure it out, but once you figure it out it is pleasant to use"*. Other participants also showed enthusiasm and a sense of accomplishment when they successfully completed tasks after struggling with them previously.

The application includes an integrated tutorial to support understanding of specific mechanics, however, the implementation of this tutorial was not always experienced positively. In the part of the tutorial where the participants practice placing and removing a wall on specifically indicated spots, it became clear that this was not universally helpful. Three participants (P1, P3, and P4) found this tutorial useful and understood the goal of the exercise, however, two others did not. They were under the impression that they had to place walls that were present in their homes, stating that *"it was unclear that we were not immediately building the living room"* (P5).

Although the previous aspect of the tutorial was sometimes misunderstood, having a dedicated tutorial prior to getting access to all the functionalities was generally found useful. For example, after completing the tutorial aspect of the system, P5 almost immediately closed the instructions as they felt confident that they would not need it. The participant seemed to clearly understand the functionalities of the system and was able to quickly recreate furniture and position them perfectly. They did however struggle with placing walls, but this was more related to the difficult and non-intuitiveness approach of the mechanic. The approach of indicating the semantic information of the furniture objects and the fenestration objects was found easy to progress through by all participants after they had performed the tasks for a second time. Only the moving of furniture and placement of walls was found to be tedious.

7.2.4 How Virtual Environments are Experienced.

When being immersed into VR for the first time and seeing their recreations most participants had an automatic reaction of amazement by the technology. P3 immediately proclaimed *"It is really weird!"*, whilst the initial reaction of P5 was *"Wow, that's amusing"*. P4 mentioned: "*Wow, it looks like as if you're at home, although I do miss the television".* An interesting finding with the remark of P4 was that initially the participant found the virtual environment to have similarities with their actual living room. However, she then answered the question if it still looks like her living room with: *"now a lot less, I do miss the actual colors I have at home … and the roof."*. Of course, being immersed into an unfinished environment does have downsides as a lot of reference points are not present.

Some participants were also preoccupied with experiencing their first immersion into VR that they had to be reminded on identifying the recognizability of their recreation. This did shine some light on the influence of feelings of presence and the effects of high immersion in their environment. A few participants did find the immersion have a realistic feel as P5 mentions that *"it is weird that you think that there is a table there, that is not actually there"* and *"because it does feel so realistic it almost let you believe that it is a real environment."*. P2 mentioned during the immersion: *"so there's the couch. That's exactly right."*. Upon asking how he experienced the immersion he said *"It is exciting. You first create your living room and then you can look at it like that."*. P3 answered the question if she had the feeling if she was actually present in the virtual environment *with "I did have the feeling that I was actually in my living room"*. The other participants were less convinced of the effects of presence, as P4 said that *"it does feel like I'm in a room, however it does not feel like that room is mine."*. P1 was on the edge, he mentioned that *"although I estimated the dimensions incorrectly* [as he created a virtual recreation that was way bigger than intended], *more or less this does look and feel like my living room"*.

7.3 Discussion

The thematic analysis revealed four main themes which were defined as: need for clear content, interaction barriers (divided into user-specific and application-design related), how virtual environments are experienced, and learning and skill acquisition. Each theme is not isolated but rather closely linked to the others and contributes to the overall understanding of the user experience of the target group with both geometric and semantic information extraction and their experiences with the reconstructed personalised immersive virtual environment. These themes help to address the final two research questions:

> RQ3: *How do the users of the target group experience the geometric and semantic information extraction?*

> RQ4: *How do the users of the target group experience the reconstructed personalised immersive virtual environment?*

7.3.1 Geometric and Semantic Information Acquisition

The need for clear content emerged as a foundational theme, as it influences how user's experience the interaction process. The clarity of content, particularly in relation to how instructions were presented to the users and how the users were navigated through the application, impacts the learning and skill acquisition aspect. If the system's content and instructions are logical and easy to understand, participants could find it easier to learn and acquire the necessary skills to navigate the virtual environment and perform the required tasks. For example, if a relatively difficult mechanic such as wall placement is properly explained and the required interactions are supported by clear task indicators, learning this mechanic could be significantly quicker which helps with acquiring the correct knowledge and skills for such an interaction. This could be done through the use of images or symbol-labeled controls, clear textual instructions related to the target group, and enlarged clickable areas. These points have been implemented into the KamerMaker system and were generally found to be logical by the users, resulting in a more intuitive learning process. This is in accord with the 'Universal Design Approach', which prioritizes the usability and accessibility of technology for all users, including people with disabilities, such as MBID (Mace et al., 1997). The appreciation for the clear button images aligns with the guideline from Seeman-Horwitz et al., (2021) about making usable (web)content for individuals with cognitive and learning disabilities. Specifically, the findings validate the positive influence of the following features on user experience and usability:

- The use of image or symbol-labelled controls, such as all the buttons that were put into the application. For example, buttons indicating specific furniture types contained a clear icon of that type accompanied by the related word of said furniture.
- A consistent and simple user interface structure, such as having the semantic indication interfaces be consistent everywhere they were implemented and keeping the amount on interactions required to a minimum.
- User input accompanied by clear instructions, such as showing the images of the button inside of the instruction texts.

The last example, however, also shows that there are instances when even with clear content focused design interaction barriers could arise, such as the inclusion of the animated hand that guides users to their next interaction. Over-guidance could lead to premature interactions, which then becomes a barrier in the interaction process. A suggested solution by a participant was to incorporate an audio-supported reading of the textual instructions as he said that made him understand the text better and quicker. Besides implementing audio-supported reading, another approach to prevent premature interactions is to have the navigational buttons only become active after the instructions have been completely read or narrated. In a scenario where both are implemented, the hand indication animation and button activity would only be triggered once the audio narration has completed so that no distraction could be present during the explanation. This provides users with the required time and space to understand and learn from the instructions.

No participant directly mentioned they found the rooms look explicitly realistic in a direct comparison with their own living room. Most indicated that it was incomplete aspects of the environment (e.g., unfinished construction, missing models, incorrect colors); however, some participants recognized the potential of realism when integrating ways to simply add more details to the room. Incorporating the user's interests, attention, and engagement could enhance the system's realism and captivation, especially when more personal objects are integrated into the virtual environment. The current iteration mainly aims to recreate contextual stimuli in the form of user's living rooms, without much emphasis on personalized contextual stimuli (Conklin et al., 2008). When individuals have a stronger emotional connection to their living room, they could have a clearer mental representation of it, helping in the identification of missing or misplaced elements in the virtual environment. This emotional connection to the environment might also make them more forgiving of imperfections.

Introducing a clear reference object at the start of the interaction could enhance the emotional connection users feel towards their living room. Ideally, this reference object would be a piece of furniture that holds significant emotional value and occupies a central place in the room. The use of a reference object could offer several benefits:

- It could address the issue raised by a user who had difficulty accurately gauging the room's spatial layout, resulting in an oversized room representation. If the user has a familiar reference object whose size they know well, this could help provide a clearer indication of the room's average element size, thereby reducing the likelihood of such errors.
- Starting the interaction process with a reference object could help mitigate the confusion expressed by a participant who was unclear about whether they were building the living room during the tutorial phase of the application.
- Integrating the use of LiDAR technology to 3D scan this reference object as the initial step in the interaction process could significantly impact users' emotional connection to the virtual environment. By having the users select and scan a personal object that holds significant emotional value, we can help create an immediate emotional bond between them and the virtual environment. This 3D scanning process would also help to create a more realistic and personalized virtual environment, but could also cause breaks in

presence as one object would look significantly different than the other objects.

Personalization was a reoccurring subject when discussing the themes as also some of the interaction barriers were caused by its absence. The following personalization-related discussion points were identified:

- One participant indicated that he was on the autism spectrum, leading to unique interaction demands. Goin-Kochel et al., (2008) and Matson & Shoemaker, (2009) discussed that there is a high prevalence of autism accompanied by intellectual disabilities. Therefore, further research into prevalent comorbidities and implementing the resulting personalized approaches into the system could significantly benefit user experience and usability for that specific group.
- Participants suggested that including a wider variety of models, such as a television, clock, painting, stairs, glass doors, radiator, specific plants, and a rug, would positively influence the user experience and usability of the application. They also expressed a desire to create a kitchen space within the virtual environment as it was an integral part of their living rooms. However, there are potential drawbacks to consider in implementing such aspects. Increasing the range of models and incorporating a kitchen space could potentially increase the application's complexity, which may overwhelm users and make it more challenging to interact with.
- Not only have these abovementioned proximal stimuli (Conklin et al., 2008) in the environment, but also personalize these specific object (e.g., specific brand of cigarettes or alcohol). Implementing such personalized proximal stimuli comes with many additional challenges. Though, with the rise of technological enhancement and the current boom of AI, new options could arise to ease this process. For example, Shap-E (Jun & Nichol, 2023) a conditional generative model for 3D assets, is capable of generating 3D models based on text. Although the results are not yet realistic enough to be implemented in a system such as KamerMaker, it does indicate the potential AI generated 3D models can have. In future KamerMaker versions, this technique could be implemented by, for example, having the users describe their living room by voice, record and transcribe these words to text, and use a Natural Language Processing-based approach to extract object-related details which need to be generated. These additions could be beneficial for enhancing the experience inside of the virtual environment.

A significant application-design-related barrier that emerged was related to the extraction of geometric information of furniture and walls. While moving furniture was not inherently problematic, the requirement to selecting the furniture prior to moving it around was found to be challenging for some participants. Additionally, the current approach for rotating furniture objects also seemed to be unintuitive. It was interesting to see that one participant, who had skipped through the instructions, interacted with the application in a way that mirrored the map rotation feature on Google Maps when trying to rotate furniture. This participant, along with others, suggested that the furniture rotation feature should emulate the one used by Google Maps. This observation underscores the importance of implementing intuitive interaction methods to reduce interaction barriers. However, if more intuitive methods are implemented, the need for immediate explanations regarding furniture movement and rotation might be reduced. It could be that the explanations regarding the movement and rotation of furniture are not necessary directly when more intuitive approaches are implemented. More research should be conducted in that case regarding tailored touchscreen interactions. It would be particularly interesting to explore whether users, without any prior knowledge of the application, would naturally move furniture by dragging it and rotate it using a gesture akin to the one used in Google Maps. Given the realization that investing time and resources in teaching users' specific mechanics may not always yield the best results, it's valuable to identify which parts of the tutorial are essential for understanding the application, and which parts might not be strictly necessary.

7.3.2 Experience of the Virtual Environments

When being immersed into the virtual environment for the first time some of the participants indicated the feeling as if they were truly in their recreated living rooms. One participant immediately indicated that she recognized their environment as their living room, but rectified later on in the experiment that this was not the case. There could be several explanations of this behavior such as that the participant was impressed by being immersed into VR for the first time and recognized a specific aspect of the room, but upon further immersion saw more of her recreation and lost that feeling. Another reason could be social desirability bias, where people give an answer that they think the researcher wants to hear.

An interesting concept that was thought-up during the experiments is how their involvement in the recreation process itself impacts the users' perception on the recreated environment. Personally reconstructing the room, and subsequently experiencing it, could positively someone's ability to recognize it as their own living space. When users are actively involved in the process of recreating their living space, they might develop a mindset that the room is already their own, even if the design has some flaws. This mindset could lead to a more seamless recognition of the space, as they might view it in a more forgiving and personal light. They may be more likely to overlook any discrepancies or imperfections in the design, as they have invested time and effort into recreating the space themselves. In other words, the sense of ownership and familiarity gotten from having personal involvement in the recreation process could result in a stronger connection to the recreated indoor space. The personal involvement could also be enhanced when incorporating elements that relate to the user's interests, attention, and engagement.

Chapter 8. Discussion

In this research we developed the KamerMaker system in which people can reconstruct their living rooms within a virtual environment using a dialogue-guided step-by-step process. This system was made to find an answer to the main research questions that has been formulated as:

> RQ: *How to reconstruct personalised indoor contextual immersive virtual environments for addictive disorders treatments for individuals with mild to borderline intellectual disability?*

With the accompanying sub-research questions:

> RQ1: *Which contexts and context-related elements elicit alcohol-related cue reactivity in individuals with AUD and MBID?*
>
> RQ2: *How can indoor spaces be reconstructed using personalised contextual information acquired from individuals with MBID?*
>
> > RQ2.1: *How can indoor spaces be reconstructed in 3D?*
> >
> > RQ2.2: *How can personalised geometric and semantic information be obtained from individuals with MBID?*
>
> RQ3: *How do users of the target group experience the geometric and semantic information extraction?*
>
> RQ4: *How do users of the target group experience the reconstructed personalised immersive virtual environment?*

This chapter will interpret the implications of the research and discuss the potential for further research in this field. Additionally, we will shed light on the limitations we encountered during the execution of our research.

8.1 Context-related elements for eliciting Alcohol-related Cue Reactivity in individuals with AUD and MBID

In order to answer the research question, *"Which contexts and context-related elements elicit alcohol-related cue reactivity in individuals with AUD and MBID?"*, we examined the concept of cue reactivity within therapies like Cue Exposure Therapy (CET) and Cognitive Behavioural Therapy (CBT). Cue reactivity refers to the conditioned responses individuals with AUD experience when exposed to alcohol-related stimuli (Bordnick et al., 2008). Contextual stimuli, such as environments where alcohol consumption occurs, can contribute to relapse in individuals with AUD, including those with MBID. Studies have shown that certain environments, like parties, restaurants, and people's homes, can heighten alcohol cravings in individuals with AUD (Ghiţă et al., 2019). Based on these findings, we decided to focus on the context of the users' homes, specifically the living room, while avoiding the inclusion of too many AUD-related items to prevent overcomplication.

While this study focused on the context of the living room, it's crucial to acknowledge that other environments may be equally or more significant for different individuals with AUD and MBID. Future research should explore the potential value of these various contexts for a system like KamerMaker. However, to effectively study these various contexts, it will be necessary to research innovative approaches for creating and implementing virtual environments that accurately represent that specific context. Moreover, it's important to note that while the initial target group included individuals with both AUD and MBID, the presence of AUD wasn't a key consideration during the application's design stages as most of the design choices were based on characteristics associated with MBID.

8.2 Indoor Space Reconstruction Containing Personalised Contextual Information

To address the research question, *"How can indoor spaces be reconstructed using personalised contextual information acquired from individuals with MBID?"* two additional questions were formulated to find a suiting answer.

8.2.1 How can indoor spaces be reconstructed in 3D?

For the first question: *"How can indoor spaces be reconstructed in 3D?"* we have explored three primary approaches to reconstructing 3D indoor models: point cloud-based reconstruction, photographic-based reconstruction, and 2D floorplan-based reconstruction. After conducting a strength and weakness analysis it was concluded that a floorplan-based reconstruction could provide the best starting point.

Alternatively, the rise of technological enhancement and the current boom of AI provides us with newer, more advanced options for recreating objects and even complete buildings. A good example is the recently presented Neural Surface Reconstruction AI model by NVIDIA called Neuralangelo[9], which is capable of creating 3D assets from videos taken by smartphones. This specific AI *"can effectively recover dense 3D surface structures from multi-view images with fidelity significantly surpassing previous methods, enabling detailed large-scale scene reconstruction from RGB video captures."* (Li et al., 2023, p. 8456). The results from this photogrammetric-based approach are promising and could be a viable approach for future adaptions.

[9] Source: https://blogs.nvidia.com/blog/2023/06/01/neuralangelo-ai-research-3d-reconstruction/

8.2.2 How can personalised geometric and semantic information be obtained from individuals with MBID?"

For the second question: *"How can personalised geometric and semantic information be obtained from individuals with MBID?"*, we conducted a literature review focusing on the unique challenges faced by individuals with MBID when interacting with technology. These challenges were compared during a strengths-and-weaknesses analysis with the previously discussed reconstruction methods to identify suitable approaches.

These unique challenges stem from both internal and external barriers, as outlined by Wehmeyer et al. (2004) and Nystedt (2019) Internal barriers are tied to individual limitations and are grouped into five domains according to Carroll, (1993): language, communication, and auditory reception; reasoning, working memory, and cognitive speed; memory and learning; visual perception abilities; and knowledge and achievement abilities. These can significantly impact the accessibility and usability of technology for individuals with MBID. External barriers, which relate to factors that obstruct the accessibility and user experience of technology (e.g., the lack of universal design features) can be addressed by implementing proactive design approaches. Approaches, such as the Universal Design Approach, aims to make technology usable by all people without the need for adaptation or specialized design (Mace et al., 1997). It's important to note that both Carroll's and Wehmeyer's research, conducted three and two decades ago resp., happened in a time where the technological landscape was extremely different than today. However, no research has been conducted in this field since then.

When looking at interaction mechanics that were not effective, significant confusion and inaccuracies could be seen during the recreation of the room walls. The conducted literature review pointed out that people with MBID generally experience difficulties with visual memory, impacting their ability to form mental representations of objects and environments (Carroll, 1993). This barrier comes into play when users are required to replicate their living room layout from memory. As seen in the results, this approach could lead to errors in terms of indicating inaccurate spatial dimensions, which hinders the users' ability for room recognition when immersed into the recreated virtual space. In previous discussions we have highlighted various approaches that could reduce these inaccuracies and mechanical misunderstandings:

- Audio-supported reading for more precise tunneling and providing a structure for better understanding the tasks.
- Introducing a clear reference object at the start of the interaction could enhance the emotional connection users feel towards their living room.

Considering the crucial role that an accurate room layout plays in recognizing a virtual environment as their own living room, a more reliable solution should consider the introduction of other reconstruction approaches described in **Chapter 4**. It should be able to extract geometric information the room layout with high spatial accuracy. Importantly, this process should require minimal effort and shouldn't require any to minimal intervention from caregivers. Given the recent advancements and investment in LiDAR scanning technology by major smartphone companies like Apple, this approach could be implemented to accurately measure the spatial dimensions. To leverage this, we could develop a new app that guides users through the process of scanning their living room. This approach would allow us to capture accurate spatial dimensions, leading to a precise reconstruction of the users' living room walls. By implementing this solution, we not only address the issues found in the wall creation process but also streamline the user experience in the KamerMaker application as a difficult mechanic is removed. This approach maintains high accuracy, providing a solid foundation for recreating furniture as you have more accurate recognition points.

Alternatively, when placing AI-based approaches such as Neuralangelo in the context of the strengths and weaknesses analysis performed in Chapter 5.4.3, it appears that such an approach has desirable outcomes. It's capability of accurately capturing the 3D geometry of a scene by using normal cameras scores high on the accuracy-related factors, whilst the user-experience related requirement is solely the making of a video of your living room. Because users can use their own smartphone, the need for additional instructions of a new device and the need for a caretaker to be present at the location of the user is not there anymore. In general, future work should invest time into incorporating new AI-based approaches. This AI-based approach was not present during the research and development stages of this research and have only been recently started their advance in the technological sector. Therefore, they have not been included in the strengths and weaknesses analysis in Chapter 5.

Mapping the layout of someone's living room could fall under the General Data Protection Regulation (GDPR)/ Algemene Verordening Gegevensbescherming (AVG) as it could be seen as a form of personal information. Therefore, it's essential that clients are fully informed about how their data is being collected, stored, and utilized. One potential method for protecting this data is through hashing. This process transforms the living room data into a unique string of characters, making the original information untraceable. The decoding of the environment would then only be possible with the correct key, adding an extra layer of security. In addition, it's important to consider the new Medical Device Regulation (MDR) and Medical Device Directive (MDD), particularly if the virtual environment is being used in a clinical context. These regulations relate to the safety and performance requirements of medical devices. While a virtual environment may not immediately be seen as a medical device, these rules could apply depending on the intended use.

8.3 Experience of Geometric and Semantic Information Extraction

The research question, *"How do the users of the target group experience the geometric and semantic information extraction?"* was addressed through an experiment followed by a thematic analysis. This analysis resulted in four main themes that paint a picture on the target groups experience. These themes are: (1) need for clear content, (2) interaction barriers, which were sub-divided into user-related interaction barriers and application design-related barriers, (3) learning and skill acquisition, and (4) how virtual environments are experienced.

The results of the analysis indicated the relevance of implementing principles from design approaches such as the Universal Design Approach (or Design for All) (Mace et al., 1997), the work in progress document by Seeman-Horwitz et al., (2021) which provides assistance on making usable (web)content for individuals with cognitive and learning disabilities, and the grouped recommendation by Dekelver et al., (2015) on developing increasing accessible and usable mobile/touchscreen applications for people with MBID. After having used them in the design process during the development of the KamerMaker system, it became evident that certain principles required additional attention, especially the principle of personalisation.

8.3.1 Personalisation

During the evaluation of the system, we encountered multiple instances where the need for more personalised approaches were desired. This need for personalisation indicates a departure from a "one-size-fits-all" approach to application design and interaction. Because of the diversity of our target group, it's clear that a single, universal solution may not effectively tailor to the needs and preferences of each individual user. For example, users within our target group not only vary in terms of their cognitive and physical abilities but also in their personal lifestyles, including potential comorbidities like substance use disorders. However, personalisation is a complex and multidimensional aspect of system design. In our context, personalisation is not just about tailoring to the unique preferences or needs of individual users. It is also about creating an application that is flexible, adaptable, and accommodating of a wide range of user interactions and experiences.

For instance, the unique interaction demands highlighted by a participant on the autism spectrum underline the necessity for *Personalised Application Settings*. These settings would not only address individual preferences but also help in making the application more accessible to users with different cognitive and physical abilities. Furthermore, the participants' desire for a broader variety of 3D models and options for semantic elements pointed towards the need for *Personalised Virtual Environment Elements*. Their suggestions, ranging from household objects like televisions and clocks to more personalised objects like specific brands of cigarettes or alcohol, indicate the importance of integrating more diverse and personalised stimuli into the virtual environment. Finally, the discussions around how users interact with the application brought to light the requirement for *Personalised Touch Interactions*. Users interact with applications in their unique ways, and acknowledging this diversity could enhance the usability and appeal of the application. This research has therefore identified three unique types of personalised requirements that are of importance in this context:

- *Personalised application settings:* which relates to the inclusion of optional application settings which influence the interaction process.
- *Personalised virtual environment elements: which* related to the inclusion of a wider variety of 3D models, such as a television, clock, painting, as well as more options for semantic elements.
- *Personalised touch interactions:* which relates to how the users interact with the application to perform specific tasks, such as the various approaches to wall creation and furniture rotation.

Personalised application settings.

There are a variety of settings on which users had conflicting reactions. For example, where some found the hand-indication animation useful, other found it very distracting. It would be beneficial to conduct research in firstly identifying all the different settings which influence the interaction process of the users, followed by the identification of the combination of starting settings that appeal to the general user. If users wish to deviate from these default settings, they should have the ability to easily and clearly make modifications. If altering these settings proves challenging, it could be possible to ask a healthcare provider for assistance in making these adjustments. However, this means that the healthcare providers would need some familiarity with the application or would require training to implement these changes. Ideally, we should facilitate an easy approach for users to make these changes themselves, while also offering the possibility of caretakers stepping in to assist. The number of optional settings should be held at a minimal though, as we do not want to overwhelm the user with a long list of settings.

- One user-suggested setting is the inclusion of audio-supported reading, which is a reading technique that combines the use of visual text with auditory support. This is typically achieved through digital text-to-speech (TTS) technology that reads aloud the text that is displayed visually (Jackson & Karger, 2015). TTS is found to positively affect reading comprehension (Wood et al., 2018), reading rate (Moorman et al., 2010), and reading endurance (Elkind, 1998); however, it should be noted that not all individuals with learning disabilities will benefit from ASR in equal ways because of their complex and heterogeneous group of conditions (Jackson & Karger, 2015).

Personalised virtual environment elements

Users have pointed out the limited variety in the models during the selection. While our current approach of 'indication-through-resemblance' does have its benefits, such as requiring significantly less cognitive load compared to other methods, the limited number of models does affect the ability to recreate a virtual environment that closely mirrors the user's own surroundings. However, incorporating a larger number of models into the application comes with its own set of challenges, as it could greatly extend the time required for users to select their preferred models. Therefore, we need to strike a balance between an expanded model library and a user-friendly selection process.

An approach that could provide highly accurate results which requires minimal effort could be the implementation of AI-based text 3D model generator, such as Shap-E (Jun & Nichol, 2023), or AI-based generators that use an image as prompt, such as 3DFY[10]. With this approach, users simply describe a particular object in text, and the AI generates it. This technique might be particularly useful within the scope of Virtual Reality Cognitive Behavioral Therapy (VR-CBT) interventions. For example, certain items, like lit cigarettes, lighters, and ashtrays for nicotine-dependence, or bottles of alcohol for AUD, could be introduced into the virtual environment. These items, known as proximal stimuli, can trigger cravings (Bordnick et al., 2008) and personalizing these items based on user input could lead to more individualized stimuli that could have a stronger effect in inducing cravings (Fatseas et al., 2015).

Using these items as reference objects, an idea we initially explored in Chapter 7.3.1, could greatly enhance the user's experience. We found that including familiar items right from the beginning of the interaction strengthens the emotional bond users have with their digital living room. In our initial discussions, we considered using LiDAR to create 3D scans of these personal items; however, this technology isn't perfect as it isn't quite able to create high-quality, realistic representations. Additionally, it meant that we'd need to go to the user's house to scan each item, which is undesirable. With the introduction of AI object generators, like Shap-E and 3DFY, we could recreate these reference objects more accurately and more conveniently. Users only need to provide textual descriptions or an image of the object, and the AI-based system can create the corresponding 3D models. Then we could either fill the room with more generic furniture models, or have the AI-generator generate the other models as well.

[10] Source: https://3dfy.ai/

Personalised touch interactions

Lastly, we should focus more on developing intuitive touch interactions to mitigate interaction barriers. However, as discussed previously, this "one-size-fits-all" approach must be improved by personalization options to cater to the unique needs of the target group. It's about finding a balance between implementing common and easy-to-understand interaction approaches as well as providing users with personalized options to suit their needs.

- Implementing commonly used touch interactions (e.g., Google Maps rotation) can make it simpler for users and should reduce their mental load. This results in reducing the need for explaining interactions mechanics in detail, reducing the number of instructions users get and speeding up the interaction process. It's important to note that flooding users with a lot of instructions from the get-go can be unhelpful.
- Investing time in identifying the mechanics of an application (e.g., wall-placement) and subsequently find interaction types that can intuitively perform this mechanic is valuable. This not only simplifies the user interface but could also result in a sense of control and independence by the user.
  Giving users the option to access explanations on the various interactions could help those who encounter difficulties or desire more information. We can't expect that each user understands the interactions that were put into an application, therefore providing them with a clear option to get information about it is valuable.
- While tooltips and instructions are common in many applications, they might not be effective for our target group. A personalization approach might involve developing adaptive tutorials or using audio-based instructions that guide the user at their own pace.

8.3.2 Hardware Selection

The use of the ACER 23" touchscreen monitor seemed to be a correct decision overall as most participants found it easy to use and didn't experience major limitations during the interaction. One participant expressed a preference for using a mouse, which indicates that individual preferences and familiarity with specific technologies can also play a role in user's experience. The potential complexity and cost of the setup could however pose a barrier to its broader adoption beyond the research setting. This brings up the potential requirement to explore the use of more commonly available and more affordable devices, which could minimize these barriers and make the application more widely accessible when deployed in care homes. Using these devices could aid the user's learning and skill acquisition as they do not have to get used to new devices beforehand, but rather could interact with more commonly known devices (e.g., iPad). It is important to keep in mind that VR headsets such as the Oculus Quest 2 might need the computational power of a PC in order to properly visualize the virtual environments in high quality. Even though it has a built-in computer, this decrease in computational power could affect the how users experience their virtual environments as it affects the user's perception, potentially reducing the sense of immersion and recognition. Other more accessible VR systems could be smartphone-based VR headsets (e.g., Google Cardboard) as no additional hardware is required to be bought.

8.4 Experience of Virtual Environment Immersion

The final question *"How do users of the target group experience the reconstructed personalised immersive virtual environment?"* relates to how the participants experienced the immersion into their recreated living room. The questions regarding this topic were based on the 14-item Igroup Presence Questionnaire (IPQ, Schubert et al., 2001) as discussed in **Chapter 7.1.4**, which assesses 'presence' based on 4 subscales: (1) general presence, (2) spatial presence, (3) involvement, and (4) experienced realism. Rather than using IPQ as a numerical rating system to measure 'presence' in a virtual environment, we used its four areas as topics of conversation during the semi-structured interview.

Spatial Presence

One aspect that has not been discussed in this research but could hold significant value for increased emotional responses to the virtual environments is owning a virtual body in the virtual environment. When a user feels embodied in a virtual avatar, they are more likely to have a strong sense of being 'in' the virtual space, rather than just observing it as they can perceive and interact with the virtual environment as if it was a real space. *"The illusion of virtual embodiment affects not only the perception of one's body but has an impact on cognitive processes: virtual body ownership, as a subcomponent of embodiment can influence our spatial perception, for example the perceived location of the real body part, spatial orientation, or the perceived size and distance of virtual objects."* (Gall et al., 2021, p. 2). Of course, additional research should be conducted regarding these virtual avatars in order to optimally implement them. It was found that the sense of agency (i.e., the feeling of control over one's own actions, and through them, the external events) is important when inducing a sense of ownership for people with MBID (Langener et al., 2022).

Expanding on the concept of virtual embodiment, to achieve a higher level of spatial presence in the virtual environment, it's important to focus on enhancing the interactive aspects of the environment. Immersion is often heightened when users can manipulate objects in the environment as they would in the real world, generating a sense of direct engagement with the surroundings. In the context of the recreated living room, this could mean enabling users to interact with furniture, appliances, and other elements in a way that mimics real-life behaviour. Important to note is that these *"possibilities to interact, be it objects or characters, can enhance presence only when they are indeed understood as such possibilities."* (Regenbrecht & Schubert, 2002, p. 431).

Involvement

It has become clear that a personal connection to the recreated living space significantly influences their perception and immersion in the virtual environment. Personalized elements, such as favourite books or distinctive pieces of furniture, were discussed to contribute to a clearer mental representation of this space, leading to a more accurate and forgiving recognition of the VR environment. Focusing more on the user's emotional connection to their environment and integrating personal details can significantly enhance the immersion experience. This can be achieved by implementing suggestions from the personalised virtual environment elements discussed in Chapter 8.3.1.

The relationship between personal involvement in the design of a virtual environment and the degree of presence experienced is an interesting, yet under-explored topic in current virtual reality research. This focusses around whether the process of personal creation of a virtual environment amplifies the subsequent sense of immersion or "place illusion" within that space. Active engagement in the recreation process of their own living space could contribute significantly to their perception of that space, as it could influence the user's tolerance towards inaccuracies or imperfections of the environment. This could result in a sense of familiarity which could make them view the environment through a more forgiving and personal lens. In contrast, when the virtual environment is designed by someone else, the user's recognition of the space and subsequent sense of presence might be affected as the environment could differ from the user's expectation. It is possible that recreations made by other means may exhibit higher accuracy and attention to detail, and could therefore increase the sense of presence and believability. However, this might come at the cost of losing the personal connection and familiarity that users experience when recreating their own living spaces. Balancing the accuracy of these approaches and user involvement could be a possible factor in improving the application. These ideas are speculative and future research is necessary to validate these assumption.

Experienced Realism

The current version of the KamerMaker system does not contain photorealistic elements, but rather models that are visibly digital. The lack of realism could have influenced the fact that the participants of this research did not experience their recreated environment as realistic. It has been discussed that the inclusion of photorealism has effect on self-reported social presence (i.e., to the sensation of being in the company of others while in a virtual environment) and place illusion (i.e., the sensation of being physically present in the virtual environment) when immersed in a virtual environment (Zibrek & McDonnell, 2019).

It's important to note that realism isn't limited to the visual domain. Multi-sensory integration can play a role in enhancing the perceived realism of a virtual environment. In the context of substance use disorders, the inclusion of olfactory cues, such as the smell of smoke for a smoker, might contribute to the perceived realism of a virtual environment. Smell has a unique capacity to trigger memories and emotional responses, often more intensely than other sensory stimuli. Therefore, users' sense of spatial presence is enhanced when simulated smells that are implemented into a VR environment (Archer et al., 2022).

8.5 Limitations

A limitation of this research is that whilst conducting the semi-structured interviews I as the researcher have accidentally asked some leading questions. This was unintentional and happened due to the flexible nature of semi-structured interviews, where follow-up questions are often spontaneously formulated based on the participant's responses. These leading questions may have induced response bias among the responses. Specifically, steering questions can unintentionally influence the respondent's answers by suggesting what the 'right' or 'expected' answer might be, which could affect the reliability of the data collected and potentially the validity of the results, as some answers may reflect my assumptions or expectations rather than the participants' true perspectives or experiences.

The Igroup Presence Questionnaire (IPQ) was adapted in this study due to the specific characteristics of our target group. To reduce the complexity of the questionnaire and to ensure that participants could effectively engage with it, it has been transformed into a semi-structured interview. The 14-item IPQ was therefore refined to contain one representative question from each sub-scale, and the questions were rephrased in a manner that was more appropriate for the target group. This approach, however, may have implications for the validity and reliability of the questionnaire as selecting only one question from each sub-scale may have oversimplified the construct of 'presence'.

Another limitation is the subjective decision on the interaction mechanics of the KamerMaker application. Although research and discussions has led to this choice, the decision to implement these mechanics were still highly subjective, meaning that future interaction issues regarding these mechanics could have been avoided. In the future, it would be smarter to divide the design process into multiple phases, where initially the mechanics and other application aspects will be tested with the target group. These can then be refined in a second iterations to ensure a more fluent interaction process.

Because some participants were not able to finish the recreation of their living room, less data on the experience of those virtual environments was collected. This situation led to a potential skewing of our results as we ended up relying on a smaller pool of user feedback than initially anticipated. With two participants this was partially due to technical issues that were encountered during the interaction process.

One technical limitation of our research concerns the choice of technology used for interaction, namely the ACER 23" touchscreen monitor. While most participants found it easy to use, the complexity and cost associated with this specific setup could potentially limit its wider adoption beyond our study. For broader accessibility, we may need to consider alternative, more affordable, and commonly used devices such as tablets like the iPad. Additionally, the computational power required to render high-quality virtual environments could be a limitation. For instance, using VR headsets like the Oculus Quest 2 would require the power of a powerful desktop PC. Future studies should focus on a more adaptive setup.

Chapter 9. Conclusion

In this research we aimed to find an answer to the main research question: "H*ow to reconstruct personalised indoor contextual immersive virtual environments for addictive disorders treatments for individuals with mild to borderline intellectual disability*?". During the course of this research, we conducted extensive literature research on the relevant topics and conducted a strengths-and-weakness analysis on various approaches regarding the reconstruction of indoor spaces in a 3D virtual environment. The recommendations that resulted from this analysis led to the development of the KamerMaker application. This system is capable of reconstructing indoor spaces through the acquisition and translation of user-indicated geometric- and semantic information. It is capable of showing the recreated virtual environment in real-time. This system uses a tunnelling interface and the directed guidance approach to limit cognitive challenges and streamline the interaction process.

Evaluating the KamerMaker system with individuals with MBID provided us with valuable insights into their unique interaction styles and requirements. The analysis of these interactions has identified key processes that could enhance future user engagement and experience. Furthermore, this evaluation has facilitated a more comprehensive understanding of the benefits and drawbacks associated with a floorplan-based approach for indoor space reconstruction.

This research seems to be the first to provide a perspective on how virtual re-creations of familiar environments can created by focussing on desired user experience and usability for this specific target group. It paves a way for enhancing future VR-CBT interventions by offering the possibility to have patients be immersed into familiar environments.

Appendix A: Diagnostic Criteria for AUD

The Diagnostic and Statistical Manual of Mental Disorder (5th edition, DSM-5, American Psychiatric Association, 2013) defines 11 diagnostic criteria for AUD. The severity of this disorder is related to the number of symptoms present in an individual and if presented as following:

- Mild: Presence of 2-3 symptoms.
- Moderate: Presence of 4-5 symptoms.
- Severe: Presence of 6 or more symptoms.

The 11 diagnostic criteria as defined in the DSM-5 (American Psychiatric Association, 2013, p.491) are:

(1) Alcohol is often taken in larger amounts or over a longer period than was intended.
(2) There is a persistent desire or unsuccessful efforts to cut down or control alcohol use.
(3) A great deal of time is spent in activities necessary to obtain alcohol, use alcohol, or recover from its effects.
(4) Craving, or a strong desire or urge to use alcohol.
(5) Recurrent alcohol use resulting in a failure to fulfil major role obligations at work, school, or home.
(6) Continued alcohol use despite having persistent or recurrent social or interpersonal problems caused or exacerbated by the effects of alcohol.
(7) Important social, occupational, or recreational activities are given up or reduced because of alcohol use.
(8) Recurrent alcohol use in situations in which it is physically hazardous.
(9) Alcohol use is continued despite knowledge of having a persistent or recurrent physical or psychological problem that is likely to have been caused or exacerbated by alcohol.
(10) Tolerance, as defined by either of the following:
   a. A need for markedly increased amounts of alcohol to achieve intoxication or desired effect.
   b. A markedly diminished effect with continued use of the same amount of alcohol.
(11) Withdrawal, as manifested by either of the following:
   a. The characteristic withdrawal syndrome for alcohol (refer to Criteria A and B of the criteria set for alcohol withdrawal, pp. 499-500).
   b. Alcohol (or a closely related substance, such as a benzodiazepine) is taken to relieve or avoid withdrawal symptoms.

Appendix B: Universal Design Principles

- *Equitable use*. Individuals with diverse abilities should be capable of using the design.
- *Flexibility in use*. The design accommodates a wide range of individual preferences and abilities.
- *Simple and Intuitive use*. The design should be easy to understand, regardless of the user's abilities.
- *Perceptible Information*. The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities.
- *Tolerance of Error*. The design should reduce error occurrences and should provide fail safe features and warnings.
- *Low Physical Effort*. The design should be used efficiently and comfortably.
- *Size and Space for Approach and Use*. The design should accommodate a variety of sizes and spaces.

Appendix C: Making Content Usable for People with Cognitive and Learning Disabilities

(1) *Help users understand what things are and how to use them.* Use icons, symbols, terms, and design patterns that are already familiar to users so that they do not have to learn new ones. People with cognitive and learning disabilities often need common behaviour and design patterns. For example, use the standard convention for hyperlinks (underlined and blue for unvisited; purple for visited).

(2) *Help users find what they need.* Make navigating the system easy. Use a clear and easy-to-follow layout with visual cues, such as icons. Clear headings, boundaries, and regions also helps people understand the page design.

(3) *Use clear content (text, images, and media).* This includes easy words, short sentences and blocks of text, clear images, and easy to understand video.

(4) *Help users avoid mistakes.* A good design makes errors less likely. Ask the user only for what you need! When errors occur, make it easy for the user to correct them.

(5) *Help users focus.* Avoid distracting the user from their tasks. If the user does get distracted, headings and breadcrumbs can help orientate the user and help the user restore the context when it is lost. Providing linked breadcrumbs can help the user undo mistakes.

(6) *Ensure processes do not rely on memory.* Memory barriers stop people with cognitive disabilities from using content. This includes long passwords to log in and voice menus that involve remembering a specific number or term. Make sure there is an easier option for people who need it.

(7) *Provide help and support.* This includes making it easy to get human help. If users have difficulty sending feedback, then you will never know if they are able to use the content or when they are experiencing problems. In addition, support different ways to understand content. Graphics, summaries of long documents, adding icons to headings and links, and alternatives for numbers are all examples of extra help and support.

(8) *Support adaptation and personalization.* People with cognitive and learning disabilities often use add-ons or extensions as assistive technology. Sometimes, extra support requires minimal effort from the user via personalization that allows the user to select preferred options from a set of alternatives. Support personalization when you can. Do not disable add-ons and extensions! Sometimes users can receive extra support through personalization.

(9) *Test with real users.* Involve people with cognitive and learning disabilities in the research, design, and development process. They are the experts in what works for them. This includes involving people with cognitive and learning disabilities in focus groups. usability tests, and the design and research team.

Appendix D: Grouped Recommendations for Developers of Mobile Applications Interfaces for People with MBID.

Grouped recommendations for developers of mobile applications interfaces for people with MBID as presented by (Dekelver et al., 2015):

Navigation and graphic design:

(1) The mobile device must have a consistent and simple menu.
(2) Controls should include an image or symbol which help to identify what they are for.
(3) Warnings and feedback should stay on the screen as long as the user does not respond to them.
(4) The device shall notify the user that it works when it is in passive mode with sounds, vibrations, or icons.
(5) User input should be minimized.
(6) Simple gestures.
(7) The user interface should have consistent and simple structure.
(8) The mobile application should be equipped by errors identification and preventing mechanism.
(9) User input should be accompanied by labels or instructions.
(10) Status indicators should not be ambiguous. For example, they should have a standard icon and a text label for turning the phone on, battery and phone signal.
(11) The size of "clickable" areas should be increased.
(12) High contrast between text and background.

Requirements to the text:

(1) In order to reduce the cognitive load and a better understanding, related images can be used.
(2) The language should be plain in a brief, concise form.
(3) Necessary to provide text alternatives for non-text content.
(4) Titles should be short and simple.

Personalization:

(1) Menu of the mobile device should be adjustable so it can adapt to the needs of users.
(2) The mobile device should prevent contact configuration so that a user can easily determine who is calling to him.
(3) The number of functions should be limited in order to avoid cognitive overload.

Appendix E: Study Brochure and Informed Consent Form

Proefpersoneninformatie voor deelname aan Virtual Reality onderzoek

Beste deelnemer,

Wij willen je vragen om mee te doen aan een onderzoek bij Tactus.

In dit onderzoek ga je je eigen woonkamer namaken in een Virtual Reality omgeving.

Het is vrijwillig om mee te doen aan dit experiment, maar hiervoor hebben we wel je toestemming nodig.

Deze informatiebrief bevat alle informatie die je nodig hebt over dit onderzoek.

Lees hem rustig door en als dat nodig wordt geacht kun je het ook nog bespreken met je partner, vrienden of familie.

Als je na het lezen nog vragen hebt over het onderzoek kun je die altijd aan de onderzoek zelf vragen. Deze gegevens staan in Bijlage A en in Bijlage B.

We zijn op zoek naar mensen die een programma willen uitproberen waarin bestaande ruimtes, zoals een woonkamer, kunnen worden nagemaakt in een virtuele wereld.

We willen onderzoeken of het programma goed werkt en in hoeverre de virtuele omgeving ook echt op jouw woonkamer lijkt! Op de volgende pagina's kun je meer informatie hierover vinden.

Als je mee zou willen doen zou dat fantastisch zijn!

Als je dat niet wilt, is dat ook helemaal prima. Het meedoen of niet meedoen heeft geen gevolgen voor jouw behandeling.

Met vriendelijke groet,

Jop Paulissen, *afstudeerder Interaction Technology*

Joanneke van der Nagel, *Psychiater Tactus en onderzoeker aan de Universiteit van Twente*

Randy Klaassen, *Assistant Professor HMI bij de Universiteit van Twente*

Simon Langener, *Gezondheidspsycholoog en promovendus aan de Universiteit van Twente*

1. Algemene informatie
   Dit onderzoek is opgezet door Tactus Verslavingszorg en de Universiteit Twente. Het wordt gedaan door onderzoekers van Tactus Rekken in samenwerking met de onderzoeker van de Universiteit Twente. Voor dit onderzoek zijn bij Tactus 3 - 5 proefpersonen nodig.

2. Doel van het onderzoek
   Wij willen weten hoe je het vindt om in een computerprogramma je eigen woonkamer na te maken en deze in de virtuele wereld te bekijken. Als deelnemer zul je meubels en muren namaken en in een virtuele ruimte neerzetten tot dat je je woonkamer helemaal hebt nagemaakt. We willen onderzoeken of deze manier van woonkamers namaken een simpel proces is en hoe realistisch de woonkamer er in de virtuele wereld uitziet.

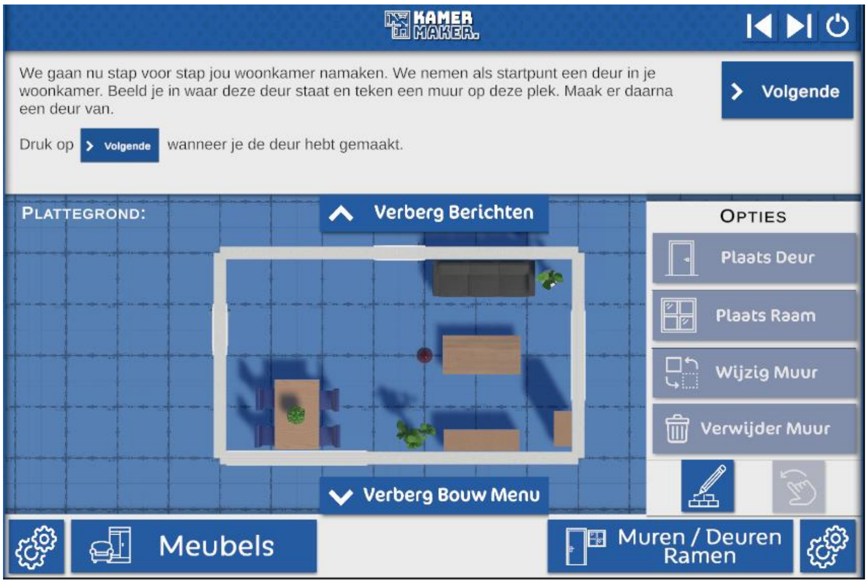
3. Achtergrond van het onderzoek
   Door makkelijk bestaande omgevingen om te zetten naar een virtuele wereld kunnen we in de toekomst veel mensen verbeterde hulp aanbieden. Samen met jou willen we er dus achter komen of deze manier goed werkt en hoe realistisch de nagemaakte woonkamers eruitzien. Daarom is jouw mening erg belangrijk voor ons!

4. Wat meedoen inhoudt
   Als je meedoet, maken we een afspraak voor het onderzoek. Dit duurt ongeveer een uur.

   De techniek tijdens het onderzoek
   Tijdens het onderzoek maak je een reconstructie van jouw woonkamer op een touchscreen scherm. Tijdens en na het maken van de ruimte krijg je soms een Virtual Reality (VR) bril op waarmee je kan rondkijken in de virtuele wereld. Deze virtuele wereld is dan jouw nagemaakte woonkamer waarin je kan rondkijken en bewegen!

De activiteiten

Je zult eerst een video zien waarin kort wordt uitgelegd wat we gaan doen. Daarna ga je bezig met het touchscreen scherm waarop het programma staat waarin je je woonkamer kan namaken. Je begint eerst met een introductie waarin je leert hoe de applicatie werkt. Hierna geven wij jou de vrijheid om je eigen woonkamer proberen na te maken door middel van de applicatie. Tijdens en na het maken van je woonkamer kun je hem in VR bekijken en aan ons aangeven hoe je de omgeving ervaart. Er wordt een schermopname gemaakt van hoe jij met het programma omgaat.



Als je klaar bent met het maken van je woonkamer gaan we door naar de volgende stap van het onderzoek. Hierin gaan we met je in gesprek over hoe je ervaringen met de het programma en stellen daarin vragen over: was de applicatie makkelijk te gebruiken? Wat kan er beter? Hierna bekijk je je gemaakte omgeving nogmaals in VR. We gaan het nu hebben over hoe echt de virtuele ruimte lijkt op jouw woonkamer. Hier krijg je een vragenlijst voor. Alle gesprekken met je worden opgenomen, zodat we het gesprek nog een keer kunnen naluisteren. Deze opnames worden niet verspreidt en blijven onder het onderzoeks team.

5. Zijn er risico's bij dit onderzoek?

De risico's van dit onderzoek zijn zeer beperkt. Soms worden mensen een beetje ziek wanneer ze een VR bril ophebben. Als dat bij jou zo is, kunnen we meteen stoppen als je dit wilt. Tijdens het dragen van de VR bril blijft de onderzoeker altijd dicht bij je. We doen dat om je te kunnen helpen als je problemen ervaart, en om te voorkomen dat je bijvoorbeeld valt of je stoot.

6. Als je wilt stoppen met het onderzoek
   Je kunt altijd stoppen tijdens het onderzoek wanneer je dat wilt door het aan te geven aan de onderzoeker. Je hoeft niet te zeggen waarom je stopt. Als er nieuwe informatie over het onderzoek is die belangrijk voor je is, laat de onderzoeker dit aan je weten. Je wordt dan gevraagd of je blijft meedoen in de toekomst.

7. Einde van het onderzoek
   Je deelname aan het onderzoek stopt als:
   - Je jouw woonkamer hebt nagemaakt en er blij mee bent.
   - Je zelf kiest om te stoppen.
   - De onderzoeksgroep, de overheid of de ethische toetsingscommissie van de Universiteit Twente besluit om het onderzoek te stoppen.

8. Vragen?
   Bij vragen kun je contact opnemen met Jop Paulissen. Als je klachten hebt over het onderzoek, kun je dit bespreken met de onderzoeker, jouw behandelend arts, of groepsleider. Wil je dit liever niet, dan kun je je wenden tot de Klachtenfunctionarissen van Tactus of de Universiteit Twente. Alle gegeven vindt u in bijlage A en B: Contactgegevens.

9. Ondertekening toestemmingsformulier

   Wanneer je voldoende bedenktijd hebt gehad, word je gevraagd te beslissen over deelname aan dit onderzoek. Als je toestemming geeft, zullen wij je vragen deze op de bijhorende toestemmingsverklaring schriftelijk te bevestigen (bijlage C). Door jouw schriftelijke toestemming geef je aan dat je de informatie hebt begrepen en instemt met deelname aan het onderzoek. Zowel jezelf als de onderzoeker ontvangen een getekende versie van deze toestemmingsverklaring.

Dank voor je aandacht.

Bijlagen bij deze informatie

A: Contactgegevens: Tactus

B: Contactgegevens: Universiteit Twente

C: Toestemmingsformulier

Bijlage A: Contactgegevens voor Tactus

Onderzoekers: Dr. Joanneke van der Nagel, psychiater
Saskia van Horsen, orthopedagoog generalist
088 382 28 87

Klachten: Klachtenbemiddeling Tactus Verslavingszorg
Antwoordnummer 851, 7400 WB Deventer
088 382 28 87

Functionaris voor de gegevensbescherming van de instelling:
Mevrouw Liesbeth ten Have-Schoonhoven
Postbus 154
7400 AD Deventer
e.l.tenhave@tactus.nl

Bijlage B: Contactgegevens voor Universiteit Twente

Onderzoekers: Jop Paulissen, Master Student
+31 623814778
j.w.h.paulissen@student.utwente.nl

Randy Klaassen, Universitair Docent
+31 534893811
r.klaassen@utwente.nl

Simon Langener
+31 534898771
s.langener@utwente.nl

Wil je graag onafhankelijk advies over meedoen aan dit onderzoek, of een klacht indienen? Dan kan je terecht bij de Ethische Commissie van EWI van de Universiteit Twente. Deze bestaat uit onafhankelijke deskundigen van de universiteit en is beschikbaar voor vragen en klachten rondom het onderzoek.

Secretariaat: Ethische Commissie (EWI):

Drs. Petri de Willingen
+31 534892085
ethicscommittee-cis@utwente.nl
Building: Zilverling 1051

Voor meer informatie over jouw rechten:

https://www.utwente.nl/en/eemcs/research/ethics/

Bijlage C: Toestemmingsformulier proefpersoon

Toestemmingsformulier voor User Test voor het onderzoek KamerMaker.

JE KRIJGT EEN KOPIE VAN DIT TOESTEMMINGSFORMULIER

Vink de juist vakjes aan. Ja Nee

Meedoen aan het onderzoek

- Ik heb de informatie over het onderzoek van XX/XX/2022 gelezen en begrepen, of het is aan mij voorgelezen. Ik heb de mogelijkheid gehad om vragen te stellen over het onderzoek en mijn vragen zijn naar tevredenheid beantwoord. ☐ ☐
- Ik stem vrijwillig in om deel te nemen aan dit onderzoek en begrijp dat ik kan weigeren om vragen te beantwoorden en dat ik me op elk moment kan terugtrekken uit het onderzoek zonder daarvoor een reden te geven. ☐ ☐
- Ik wil meedoen aan dit onderzoek. ☐ ☐

Gebruik van informatie tijdens het onderzoek.

- Ik begrijp dat de informatie die ik geef gebruikt word voor een onderzoek voor een master Thesis voor de opleiding Interactive Technology. ☐ ☐
- Ik begrijp dat verzamelde persoonlijke informatie over mij, zoals mijn naam, niet worden gedeeld buiten het onderzoeksteam om. ☐ ☐
- Ik begrijp dat verzamelde audio opnames niet worden gedeeld buiten het onderzoeksteam om. ☐ ☐
- Ik begrijp dat verzamelde touchscreen log data niet worden gedeeld buiten het onderzoeksteam om. ☐ ☐
- Ik ben het ermee eens dat mijn informatie kan worden geciteerd in onderzoeksresultaten. ☐ ☐

Toestemming voor opnames

- Ik ben het ermee eens dat er audio wordt opgenomen. ☐ ☐
- Ik ben het ermee eens dat de interactie met het touchscreen worden opgenomen. ☐ ☐

Appendix F: Experiment Procedure and Interview Questions

Ontvangst, Onderzoek Introductie en Consent Aanvraag

□ Heet deelnemer welkom en bedank voor het meedoen aan het experiment.

□ Benadruk dat zijn deelname mensen in de toekomst beter zal kunnen helpen.

□ Vraag of alles van de brochure duidelijk was.

Q: Je hebt de brochure van te voren ingezien. Welke vragen mag ik hierover nog beantwoorden?

□ Vraag of er nog andere vragen zijn over het onderzoek.

Q: Welke andere vragen mag ik nog beantwoorden over het onderzoek?

□ We pakken er nu een consent form bij en lopen deze met de deelnemer nog eens door.

Q: Welke vragen mag ik beantwoorden over het consent form?

□ We laten de deelnemer het consent form nu ondertekenen. Ze krijgen zelf ook een kopie hiervan mee.

□ Laat de deelnemer zien waarmee hij gaat werken (touchscreen scherm waarop hij mag drukken, en de VR bril waarin hij rond kan kijken)

□ Leg aan de deelnemer uit dat hij zo gaat beginnen met het onderzoek. Volg de instructies op die op het scherm staan en maak duidelijk dat wanneer ik zeg dat we even stoppen, dat er dan wat vragen komen.

□ Leg uit dat hij tijdens het interacteren hard op mag denken, en dat hij vragen zo breed mogelijk mag beantwoorden, er zijn geen foute vragen.

□ Vraag of de procedure duidelijk is.

Q: Welke vragen mag ik nog beantwoorden over de procedure?

□ Start de scherm opname en audio opname.

□ Laat de deelnemer beginnen met de interactie.

Dialoog en Navigatie van het Systeem

De proefpersoon gaat in deze fase leren hoe je door de tekst heen kan bladeren en ervaart de manier waarop het systeem met hem communiceert. Hij krijgt vier stukjes tekst te zien waar hij doorheen kan bladeren door middel van de 'Verder' en 'Terug' knoppen.

 Stop de deelnemer met de interactie vlak voordat hij een meubel gaat maken.

Q: Je hebt zojuist gezien hoe het systeem aan je vertelt wat je moet doen en hoe je door de informatie kan gaan. Ik ben benieuwd, wat vond je van de manier waarop je instructies krijgt?

 Wanneer er niet genoeg over de dialoog is gezegd:

[Dialoog] Q: In hoeverre heb je het gevoel dat de tekst duidelijk genoeg is?

- ➔ [A: positief/negatief] Q: Kun je uitleggen waarom je het zo ervaarde?
- ➔ Q: Wat vond je van de manier waarop het geschreven is?
- ➔ Q: Wat vond je van de manier waarop een knopplaatje in de tekst wordt gezet?

 Wanneer er niet genoeg over de navigatie is gezegd:

[Navigatie] Q: Wat vind je van de manier waarop je door de tekst heen gaat met de knoppen aan de zijkant.

- ➔ [A: positief/negatief] Q: Kun je uitleggen waarom je het zo ervaarde?
- ➔ Q: In hoeverre heeft het geanimeerde handje wat de plek van de knoppen aangeeft nut?

Q: Welke andere opmerkingen heb je nog over deze twee punten?

 Ga door met de interactie, totdat ik weer stop zeg.

Meubels Maken en Manipuleren [M1S0 -> M1S10]

De proefpersoon gaat in deze fase leren hoe je meubels maakt en hoe de manipulatie van deze meubels werkt. Eerst kiest hij welk meubel hij wilt maken, vervolgens kiest hij de kleur van dit meubel, daarna kiest hij een meubel wat het meest lijkt op wat hij thuis heeft staan. Het meubel komt nu in de 'plattegrond' te staan waarna hij het meubel naar een specifieke plek met verplaatsen, en hem moet draaien door er twee maal snel op te drukken.

 Stop de deelnemer met de interactie vlak voordat hij een muur moet maken [M1S10].

Q: Je hebt zojuist een meubel gemaakt, hem verplaatst in de ruimte, en hem gedraaid. Nu ben ik benieuwd naar wat jij van dit proces vindt. Hoe ervaarde jij dit?

[Maken] Q: Hoe ervaarde je het maken van een meubel? (lastig, onduidelijk, simpel …)

- ➔ [A: positief/negatief] Q: Kun je uitleggen waarom je het zo ervaarde?
- ➔ Q: [X] Ik zag dat je even vast zat bij [NOEM INTERACTIE]. Waar had je specifiek problemen mee? Hoe denk je dat het beter had gekund?

[Manipulatie] Q: Hoe ervaarde je het verplaatsen en draaien van een meubel?

- ➔ [A: positief/negatief] Q: Kun je uitleggen waarom je het zo ervaarde?
- ➔ Q: [X] Ik zag dat je even vast zat bij [NOEM INTERACTIE]. Waar had je specifiek problemen mee? Hoe denk je dat het beter had gekund?

 Ga door met de interactie, totdat ik weer stop zeg.

Muren, Deuren en Ramen Maken en Manipuleren

De proefpersoon gaat in deze fase leren hoe je muren maakt en hoe de manipulatie van deze meubels werkt. Eerst klikt hij op de knop om een muur te maken, gevolgd door het kiezen van welk materiaal de muur is gemaakt. De proefpersoon kiest daarna de kleur van de muur, waarna hij uitgelegd krijgt hoe je muren in de 'plattegrond' kan neerzetten. Wanneer er een muur is gebouwd leert hij hoe hij muren verwijderd, en hoe hij ramen en deuren in de ruimte kan neerzetten.

□ Stop de deelnemer met de interactie vlak voordat hij in VR moet gaan kijken [M3S19].

Q: Je hebt zojuist een muur plaats en een deur en een raam in de muur gezet. Hoe ervaarde je het maken van deze onderdelen?

[Muur] Q: Wat vind je van de manier waarop je een muur moet maken?

- ➔ [A: positief/negatief] Q: Kun je uitleggen waarom je het zo ervaarde?
- ➔ Q: [X] Ik zag dat je even vast zat bij [NOEM INTERACTIE]. Waar had je specifiek problemen mee? Hoe denk je dat het beter had gekund?
- ➔ Q: Hoe ervaarde je het 'Opties' menu wat aan de zijkant verschijnt?

[Deur] Q: Wat vind je van de manier waarop je een deur moet maken?

- ➔ [A: positief/negatief] Q: Kun je uitleggen waarom je het zo ervaarde?
- ➔ Q: [X] Ik zag dat je even vast zat bij [NOEM INTERACTIE]. Waar had je specifiek problemen mee? Hoe denk je dat het beter had gekund?

[Raam] Q: Wat vind je van de manier waarop je een raam moet maken?

- ➔ [A: positief/negatief] Q: Kun je uitleggen waarom je het zo ervaarde?
- ➔ Q: [X] Ik zag dat je even vast zat bij [NOEM INTERACTIE]. Waar had je specifiek problemen mee? Hoe denk je dat het beter had gekund?

□ Stel voor om een kleine korte pauze te nemen om alvast te bespreken wat we zo gaan doen.

□ We gaan zo de ruimte in VR bekijken om te zien hoe het eruit ziet.

□ Vragen of ik hij nog vragen heeft.

□ Slok water of koffie en vragen hoe het gaat.

VR tijdens bouwen

Als de korte pauze is afgelopen en hij geen vragen meer heeft over de volgende stap, gaan we verder met de interactie. Hier moet hij de plek aangeven vanuit waar hij wilt kijken en de VR omgeving gaan aanschouwen.

□ Stop de deelnemer met de interactie vlak nadat hij in VR is geweest [M3S20].

Q: Je hebt zojuist in de applicatie aangegeven vanaf welke plek je wilt kijken en daarna de ruimte in VR kunnen zien. Hoe ervaarde je dit?

[Locatie aangeven] Q: Hoe ervaarde je het aangeven van een plek in de kamer?

- ➔ **[A: positief/negatief] Q:** Kun je uitleggen waarom je het zo ervaarde?
- ➔ **Q:** [X] Ik zag dat je even vast zat bij [NOEM INTERACTIE]. Waar had je specifiek problemen mee? Hoe denk je dat het beter had gekund?

[In VR zien] Q: Hoe ervaarde je het zien van je kamer in VR?

- ➔ **[A: positief/negatief] Q:** Kun je uitleggen wat je goed/slecht vond?
- ➔ **Q:** Was het makkelijk om de VR headset op te doen?

□ We gaan nu verder met de interactie.

Vrije interactie

Nu geven we aan dat de proefpersoon het opwarmertje heeft gehad en dat alle functionaliteiten zijn uitgelegd. Nu mag hij zijn woonkamer gaan namaken zonder dat ik hem onderbreek. Ik geef nu ook duidelijk aan dat als hij vast loopt of iets moeilijk vind het aan mij moet aangeven, zodat ik kan vragen wat er specifiek onduidelijk is.

Q: Je geeft aan dat je vast zit bij [NOEM INTERACTIE]. Waar komt het door dat je niet verder komt?

- ➔ Ik leg nu uit hoe de eigenlijke interactie zou moeten.

Q: Nu ik het voor heb gedaan, kun je mij vertellen hoe het beter had gekund zodat het duidelijker was?

- ➔ We gaan door met de interactie.

 Als de kamer is nagemaakt [M5S33] stop ik de deelnemer voor de laatste paar vragen over de interactie.

Q: Je hebt zojuist in de applicatie je woonkamer nagemaakt door de vragen te volgen die aan je werden gesteld. Hoe ervaarde je dit?

- ➔ [A: positief/negatief] Q: Kun je uitleggen wat je goed/slecht vond?
- ➔ Q: In hoeverre vond je dat de manier waarop jou vragen werden gesteld handig?
- ➔ Q: Wat is in het algemeen je mening over het systeem? (makkelijk of moeilijk)
- ➔ Q: Hoe zou jij het systeem beter kunnen maken?

 We gaan nu naar het laatste gedeelte. Kijken hoe hij de ruimte ervaart.

VR Presence

Ik leg uit dat hij nu zijn gemaakt kamer in VR mag gaan zien en dat ik vragen ga stellen over hoe hij vind dat dit eruit ziet. De vragen zijn gebaseerd op de IPQ questionnaire.

Q: In hoeverre had je het gevoel dat je aanwezig was in je eigen woonkamer terwijl je in de virtuele wereld was?

[Als de vraag onduidelijk is] Q: Had je het gevoel dat de VR wereld als echt zou kunnen worden beschouwd?

[Spatial Presence] Q: Had je het gevoel meer bezig te zijn in de virtuele ruimte, dan dat je iets van buitenaf aan het bedienen was?

[Involvement] Q: Hoe bewust was je van de echte omgeving?

[Realism] Q: Hoe echt kwam de virtuele omgeving over op je? Lijkt het op je woonkamer thuis?

- ➔ Q: Wat leek wel realistisch? Wat leek onrealistisch?

Q: Welke aspecten van de virtuele ruimte vond je wel op je woonkamer thuis lijken en welke niet?

Afsluiting

□ Nadat we klaar zijn met de laatste vragen geef ik aan dat het onderzoek afgelopen is.

□ Benadruk de waarde van zijn input en bied hem wat lekkers aan.

□ Daarnaast vraag ik of hij op de hoogte gehouden wil worden van de resultaten van het onderzoek, en dat ik een video ga opsturen waarin ik de resultaten piekfijn uitleg.

□ Als er tijd is en de client wil nog even kunnen we vragen of we naar zijn kamer kunnen gaan en kijken in hoeverre de virtuele ruimte lijkt op zijn echte kamer.

□ We nemen afscheid en gaan door naar de volgende deelnemer.

Appendix G: Overview of Codes and Themes.

Theme: Learning and Skill Acquisition.
Growth in confidence after recalling solution to task. Unclear explanation of tutorial mechanics. Didn't understand instruction due to unclear explanation. Positive reaction to recalling previously learned solutions to tasks. Getting used to placement mechanics Confusion during tasks with many steps. Verbal enjoyment on positive recall.
Theme: How Virtual Environments are Experienced
Immediately wants to make changes after Immersion Immediate signalling of incorrect furniture placement Virtual environment out of proportion Recognizing certain room identifiers Recognizing the layout of the room Amazed by the technology Feeling as if they are in the actual room Feeling as if they are not in the actual room Recognizing the room on initial immersion
Theme: What user's want during the interaction
Make interactions more like well-known interactions Audio support of the text More practical approaches instead of reading Single-step processes
Theme: User Interface and Semantic Indication Experience
Clear understanding of the instructions for semantic information indication. Logical sequence for selecting models Wants more broader catalogues for furniture model selection. Difficulty in finding suitable furniture model. Positive reaction on implementation of model selection. Different model creation approach advise. Broader colour/texture selection. Clear implementation of the navigation bar. Clear sequence of selecting colour for furniture. Buttons for furniture selection are clear and easy to follow. Autistic tendencies hinder task completion because exact model is not present
Theme: Interaction Barriers
User has perfectionism Autism requires user to have everything perfect. Language and communication barriers Difficult spatial judgement Dealing with setbacks Lack of Familiarity with Technology Technical Limitations of the system Unclear rotation mechanics Request for quicker progression More types of interaction approaches Distracted by moving elements Lack of guidance on interaction process Autistic tendencies hinder task completion Unclear rotation mechanics Wall creation mechanic unclear unintuitive

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