MULTIZEN

A multisensory installation designed for individuals with profound intellectual and multiple disabilities

Master's thesis in Computer science and engineering

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CHALMERS UNIVERSITY OF TECHNOLOGY
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Abstract

Multisensory environments are today being used as a form of alternative therapy available for people with profound intellectual and multiple disabilities where the focus lies on creating a relaxing and positive experience for these individuals. However, many installation within these environments can consists of switch-like interactions which can offer the user less exploration and playfulness compared to more dynamic installations. The aim of this thesis is to shed some light on which aspects to consider when designing multisensory installations for people with profound intellectual and multiple disabilities. The thesis was conducted in collaboration with Eldorado, where members of the staff participated due to the target group not being available as a result of COVID-19. The results showed that important aspects to consider include: stimulating more than one sense, customizing for different capabilities, having a clear mapping between input and output, balancing the level of complexity in the interaction as well as having an installation that both looks and feel appealing to the user.

Keywords: multisensory environments, installation, profound intellectual and multiple disabilities, music therapy

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Abbreviation

DD = development disability

ID = intellectual disability

MSE = multisensory environment

PIMD = profound intellectual and multiple disabilities

1 Introduction

Intellectual disability (ID), commonly known as mental retardation, is a disorder that is characterized by a significant decrease in intellectual functioning and behaviour (Contreras, Garcia Bauza, & Santos, 2019). When talking about people with ID, it is easy to overlook the fact that they rarely are affected by this disability alone. In most cases, individuals with ID also suffer from severe motor impairments and other sorts of dysfunctions, such as visual and auditory impairments (Roemer, Verheul, & Velthausz, 2017). People with more severe mental disorders and motor functions are commonly referred to as people with profound intellectual and multiple disabilities (PIMD).

According to WHO (2007) the majority of all countries (81.6 %) have a policy or programme in place to address ID. The most prominent areas in which these agencies operate includes education, health and social welfare. The result of one of these policies can be seen in Sweden, where the city of Gothenburg has invested in a special department whose purpose is to provide a meeting place with activities, knowledge and culture for individuals with ID. In order to achieve this, the department, which goes by the name Eldorado, uses a combination of daily activities and educational programmes that targets both the person affected by PIMD as well as their accompanying relative or caretaker. The type of activities they offer ranges from meetings for music or sign language to tutoring in activity and communication (Eldorado, 2020). One of the core pillars of Eldorado consists of five multisensory environments, where individuals with PIMD and their accompanier can engage and experience a plethora of different interactive installations. The environments differs in the way they look and feel as they try to target different positive emotions and experiences in their users. One of these rooms is the music room, where different instruments have been gathered in order to allow people to express their feelings and identities through the means of music.

Music is not only used as a form of entertainment, but rather, it can also be used as a therapeutic method in order to increase the overall well-being of people with PIMD. Although ID usually lasts throughout a lifetime (National Institutes of Health, 2018; Lee & Harris, 2004; CDC, 2019), treatments such as music therapy can be used in order to address social, cognitive and psychological needs of these individuals. Examples of potential outcomes include reduced stress levels (Poquérusse et al., 2018), increased body and spatial awareness (Hooper, Wigram, Carson, & Lindsay, 2011) and providing a safe place for individuals to express their emotions (Rickson et al., 2014).

1.1 Problem Description

ID is the most common developmental disorder and is present in 1 to 3 percent of the worlds population (Armatas, 2009; Roeleveld & Zielhuis, 1997). According to Roemer et al. (2017), people affected by PIMD often experience feelings of separation, emotional stress and physical pain throughout their lives and many of these individuals have limited possibility to cope with these experiences. The World Health Organization (WHO) has expressed that those may be some of the most difficult living conditions in the world (WHO, 2007), the reason being systemic discrimination and the absence of judicial protection.

A study done by Sheehan et al. (2015) has shown that the amount of prescribed medicine for individuals with ID is higher than what is actually required for the documented mental illness. Dixon and Gentile (2017) also mention the fact that the use of psychotropic drugs can have more serious side-effects for people with ID compared to the general population, suggesting that alternative ways of treatment are to prefer. Some of the treatments to consider involves positive behavioural interventions, psychotherapy and work with social and environmental aspects. A multisensory environment is part of a positive behavioural intervention and the installations used to stimulate people with PIMD in those environments are created to stimulate their different senses. Incorporating stimulation of different senses is in order to create a positive emotion within the users and as such create an enjoyable social environment, alleviating the users from stress or concerns, even if only for a moment. However, several installation created for people with PIMD tend to rely on micro-switch interaction where the system is either ON or OFF. With no gradual form of input, some aspects of exploration and joyfulness that comes with more dynamic systems are lost (van Delden et al., 2019; Caltenco et al., 2012). Considering this, a greater amount of positively stimulating installations and environments customized for these individuals which allow for more interaction are needed in order to alleviate and counteract possible accumulated negative emotions, which can set a base for a more positive behavioural change and increased well-being.

1.2 Research Question

In order to create a more diverse and stimulating environment for individuals with PIMD, the creation of new and dynamic installations would be beneficial. To get a better understanding of how a multisensory instrument should be designed in order to increase the level of positive experience for people with PIMD, the following question has been posed:

> *Which factors should be considered when designing a multisensory installation for individuals with profound intellectual and multiple disabilities in order to create a positive experience?*

Here, positive is defined as something enjoyable or engaging, or something that spurs curiosity, while the aspect of multisensory refers to the tactile, auditory and visual senses.

1.3 Aim

The purpose of this thesis is to create an installation which incorporates auditory, visual and haptic stimulation to arouse a positive emotional response in people with PIMD. By observing the user group's interaction with the installation and interviewing staff members at Eldorado, this thesis aims to investigate what factors should be considered when designing a multisensory instrument for a positive user experience.

1.4 Delimiter

The scope of the thesis will only cover the senses of vision, hearing and touch. As such, whether or not taste or smell can be used in order to create a positive experience when used in combination with a multisensory installation will not be investigated. The design will also only consider physical interaction, such as touch and pressure; although other technologies such as motion capture, speech recognition or eye tracking could have been used, these were not included in order to narrow the scope of the thesis.

The primary goal of the thesis is not to design a multisensory installation that will be used as a therapeutic tool. Although this is a possible outcome of the thesis, the focus will be on creating an entertaining artifact that evokes a positive experience in the user. It is important to clarify that the target group in this case is individuals with PIMD, which does not include their accompanying caretaker or potential therapist. Thus the results of the thesis is mainly applicable for this group of users.

The physical space where the installation will be implemented is, per request of Eldorado, restricted to a wall. As such, other possible physical spaces for creating the installation were not considered.

2
Background

This chapter of the thesis provides a background of multisensory environments, what intellectual disability is and what kind of treatments exist today. It will also include related work in relation to multisensory environments and the type of installations they can include.

2.1 Developmental Disability

Developmental disability (DD) is a term used to describe disorders that include limitations to cognitive or physical functioning, or both (Verlenden, Bertolli, & Warner, 2019). A study done in the United States of America (Zablotsky et al., 2019) has shown that as many as 16 - 18 % of all children have some sort of developmental disability. The type of disorders identified in the study includes attention-deficit/hyperactivity disorder (8.5 % – 9.5 %), autism spectrum disorder (1.1 % – 2.5 %) and intellectual disability (0.9 % – 1.2 %).

The causes behind DD can vary to a great extent. Some examples include genetic or physical causes such as autism, cerebral palsy (National Institutes of Health, 2018) and Down syndrome (Ainsworth & Baker, 2004); others include environmental or parental influence like lack of stimulation, adult responsiveness (National Institutes of Health, 2018), malnutrition and maternal drug or alcohol use (Armatas, 2009). DD develops before adulthood, which is defined between the age of 18-22 (National Institutes of Health, 2018; AAIDD, 2019), and usually persists throughout a person's lifetime (National Institutes of Health, 2018; Lee & Harris, 2004; CDC, 2019).

2.1.1 Intellectual Disability

ID is a hyponym of DD and refers to disorders characterized by a significant decrease in intellectual functioning and adaptive behaviour (Contreras et al., 2019). The American Association on Intellectual and Developmental Disabilities (AAIDD, 2019) has defined ID as having an IQ value of less than 75 in combination with limitations to conceptual, social and practical skills. Examples of such practical skills includes managing schedules, routines and social interactions (Verlenden et al., 2019). The names used in order to describe intellectual disability has changed multiple times during history, as these names tend to get stigmatized. Names such as imbecile, moron and idiot are no longer considered formal descriptions (Lee & Harris, 2004), with mental retardation getting less popular as well, with more and more institutions updating their names in accordance to today's standard (Tassé & Grover, 2013; Federal Register, 2013). As such, intellectual disability will be the term used throughout this thesis

ID can range in severity, going from mild to profound. Lee and Harris (2004) estimates that around 85 % of all people with ID has mild symptoms, 10 % has moderate, 3 % to 4 % has severe and 1 % to 2 % has profound limitations. Mild symptoms includes limitations to social aspects and can as such be hard to detect at an early age. Individuals with a mild disability can in many cases live independently or with minimal external support. For moderate symptoms, the social limitations starts to become apparent and it is not unusual for these individuals to communicate using sign language or language supporting devices. Moreover, moderate ID can also include limitations to motor coordination. Severe ID is similar to moderate from a clinical aspect, but the amount of individuals with motor impairment is much higher and the limitations are more extensive (Lee & Harris, 2004). Individuals with profound ID have a very limited language comprehension and are generally limited to simple commands and requests. Beyond language and motor impairments, as many as 85 % of these individuals also suffer from visual impairment and 25 % to 33 % from auditory impairment (Roemer et al., 2017). Due to these limitations, a structured environment together with external aid is necessary for these individuals. An individualized relationship with a caregiver is emphasized in order to facilitate optimal development (Lee & Harris, 2004).

2.2 Treatments

A multiple of different methods have been developed and evaluated in order to increase the well-being of individuals with PIMD. Some of these includes medication, therapy and environmental stimulation. Although PIMD is usually a lifelong disability, interventions from a young age can help to stabilize or even improve the conditions (Lee & Harris, 2004).

2.2.1 Historical Treatments

The history of ID is imprinted with horrific examples of abuse and mistreatment. Individuals with ID were for a long time seen as being lesser humans. In prehistoric time, it was believed that mental illness was a result of the possession of demons or evil spirits. One treatment that was conducted included trephination, which is the surgical procedure of drilling a hole in the skull (Hussung, 2016). The ancient Greeks were one of the first cultures to connect the mind with the body and discarded the old view of magical beings as the cause for mental illness (Hardy, 2015). By the time of the Middle Ages, individuals with mental disabilities were treated with fear, disgust and shame. Special facilities called asylums started to pop up sometime during the 1300 century around the world, with one of the most infamous ones being London's Bethlem Royal Hospital, also known as Bedlam. The asylums were not primarily used as a place for treatment, but rather, they were used as a way to hide and remove people with mental illness from the society (Guest, 2017).

It was not uncommon that patients at these institutions were chained to beds and walls (Guest, 2017), put on display for people to view (Hardy, 2015), or treated with ice baths, sedatives and purging (Hussung, 2016).

As late as the 1950s, lobotomy was still the choice of treatment for people with mental illnesses. The procedure includes shocking the patient into a coma, whereby a tool similar to an ice-pick was hammered in through the top of each eye socket in order to reach and cut the neurons that connects the frontal lobe with the rest of the brain (Foerschner, 2010). Luckily, this procedure was abandon shortly after with the introduction of psychoactive drugs.

Although the life standard of these individuals has improved tremendously in the last 50 years alone, with implementations of new regulations and a change in attitude in society (Richard, 1990), more work is needed in order to get their level of well-being to the same level as the remaining population.

2.2.2 Psychotropic Medication

Psychotropic medications are drugs which affect emotions, behaviours and mind, it is a term which includes several different kinds of commonly prescribed drugs as well as misused drugs (Ghoshal, 2019). A lot of individuals with ID tend to have multiple medical conditions which can complicate the use of prescribed drugs. Regardless of this known circumstance, people with ID are the most medicated patient population in both the community and institutions (Dixon & Gentile, 2017). Problematic behaviour is the most recurrent reason of morbidity, mortality and for psychiatric hospitalisation among people with ID, and one of the biggest reasons many physicians concur on antipsychotic medications being an appropriate intervention for people with PIMD. An appropriate use of antipsychotic medications can help reduce self-injury and compulsive or repetitive behaviour; reduced agitation, improved sleep hygiene and increased social awareness are part of the outcome when correctly medicating with antipsychotic medications (Dixon & Gentile, 2017). Sheehan et al. (2015) writes about a high rate of prescriptions in the UK primary care, explaining that psychotropic drugs are important in the management of certain psychiatric conditions. However, they also mention that people with ID are treated with psychotropic drugs at a higher rate than necessary for the recorded mental illness. Dixon and Gentile (2017) writes that individuals with ID can be more vulnerable to side effects and thus prescriptions should be given with caution.

Before deciding on a psychotropic medical treatment, non-pharmacological interventions customized for people with ID should be considered. This includes psychotherapy, positive behavioural interventions or looking to the social or environmental factors (Dixon & Gentile, 2017).

2.2.3 Music Therapy

In an attempt to summarize all of the benefits that music therapy can have, Hooper, Wigram, Carson, and Lindsay (2008) conducted a literature review where they looked through sources dated between 1943 to 2006. Hooper et al. (2008) describes how it was demonstrated that even before the 1930, music had an important role in the treatment and the diagnosis for children with ID.

Six different categories were identified as the main purpose behind the participation in music therapy for individuals with ID: *fulfilling basic needs, developing a sense of self, establishing or re-establishing interpersonal relationships, developing specific skills, dispelling pathological behaviour*, and *developing an awareness and sensitivity to the beauty of music*. The fourth category, developing specific skills, partly overlaps with all of the others and thus is arguably an underpin for the general purpose of music therapy for this target group (Hooper et al., 2008). This category is described as involving the acquisition or development of skills, allowing the individual to act with greater independence. These skills and competences would include cognitive, physical, emotional, social or communicative development (Hooper et al., 2008). In the review, two types of musical therapy techniques are described, *active music therapy* and *receptive music therapy*. Active therapy implies that the patient is involved in creating the musical content as well as sharing vocal or/and instrumental ideas, while in receptive therapy the patient listens and then responds verbally, silently or with help of any other modality to the experience (Hooper et al., 2008).

Hooper et al. (2008) states that music activity therapy and improvisation is part of the active music technique. They continue to explain that improvisation is an alternative for people with ID to externalize and represent emotions, where the main ones are sadness, melancholy and anger. However, Bruscia (2013) describes improvisation as a means for emotional expression, without exclusion, and as a representation of feelings which may be unconscious or can not be expressed verbally. Improvisation is a form of play which allows the improviser to follow his/her own impulses, and as such, it results in a great feeling of pleasure and gratification (Bruscia, 2013). Further, other studies have shown that music provides a safe place for expressing emotions and practice teamwork (Rickson et al., 2014), reduces stress levels and increases overall well-being (Poquérusse et al., 2018).

One of the most vital parts in music therapy is the music instrument. As many of the traditional instruments lacks suitable affordances for individuals with PIMD, digital instruments are needed in order to provide a customized and enjoyable experience for this group of users. Although digital instruments comes with a lot of possibilities, the biggest challenge is to contain these possibilities within an interface that is easy to use for people with limited motor skills (Jense & Leeuw, 2015).

2.2.4 Multisensory Environments

A multisensory environment could be described as an entity which makes use of the environment and sensory artefacts in order to mix and create a new sensory stimulating experience. These environments usually include interventions with audio, visual, haptic, aromas and motion in order to enable an individual with DD to find calmness or impetus (Caltenco et al., 2012).

A multisensory environment is according to Pagliano (1999) hard to define, as the typical description can ignore important but abstract aspects. They have conventionally been defined as a certain type of environment with constellations of apparatus and resources, however this is a definition which Pagliano (1999) means can only describe a limited part of what a multisensory installation is. Furthermore, he emphasizes that the level, type and combinations of different sensations is what should be of relevance when defining the concept. The sensations should, in combination, suffice to rouse an individual's interest. It is also described as follows:

> This new MSE [multisensory environment] is a dedicated space or room for relaxation and/or work, where stimulation can be controlled, manipulated, intensified, reduced, presented in isolation or combination, packaged for active or passive interaction, and temporally matched to fit the perceived motivation, interests, leisure, relaxation, therapeutic and/or educational needs of the user. (Pagliano, 1998, p. 107).

Furthermore, Caltenco et al. (2012) explains that these type of artefacts are used to build environments which aims to initiate changes in arousal in an individual. Parts of the goal is to reduce anxiety, physical and emotional pain and affect the relaxation process of the individuals.

According to Pagliano (1999), the 'sensory cafeteria', a work by Charles Clark and Charles Cleland in 1966, could be seen as the progenitor of multisensory environments. This environment made use of sensory stimulation to elicit a variety of responses and was the ground for the later created Snoezelen environment.

2.2.4.1 Snoezelen

One type of multisensory environment which was initiated in the late 1970s in the Netherlands are the so called Snoezelen rooms. Snoezelen is a portmanteau made up of two Dutch words: snuffelen (to snuggle or to sniff) and doezelen (to doze or snooze) which (Pagliano, 1999) means was a development of the 'sensory cafeteria' described by Charles Clark and Charles Cleland in 1966. The purpose of these rooms are to both give the participant an environment where they can engage in different sensory experiences while at the same time provide a safe and relaxing environment for them. As such, the nature, quantity, arrangement and intensity of the stimulation within these rooms are carefully controlled, often by an accompanying facilitator (Lotan & Gold, 2009). Looking at anecdotal reports provided by facilities in different countries, it is reasonable to say that the Snoezelen might have a therapeutic effect on individuals with ID. The development of Snoezelen has mostly resulted in a recreational implementation approach as a support for people with intellectual and development disabilities (Lotan & Gold, 2009). Lotan and Gold (2009) mention how this can have a positive effect on maladaptive behaviour of people with ID.

2.2.5 Image Compositing

Pedersen (2013) recites Thomas Porter's and Tom Duff's compositing algebra which revolves around how to work with combining images and the visual result of it. The work of Porter and Duff speaks of several different ways to combine images and several different results from these combinations, the outlined combinations which they speak of can be seen in figure 2.1, with a visual representation portrayed in figure 2.2. Even though this way of working with compositing of images is refereed to as alpha blending, the concept of Porter and Duff is not about how to blend two entities but rather on how to overlay, trim and combine them (Pedersen, 2013).

	[s]	[d]	[b]
Src	*s*	0	s
Atop	0	*d*	s
Over	*s*	*d*	s
In	0	0	s
Out	*s*	0	0
Dest	0	*d*	d
DestAtop	*s*	0	d
DestOver	*s*	*d*	d
DestIn	0	0	d
DestOut	0	*d*	0
Clear	0	0	0
Xor	*s*	*d*	0

Figure 2.1: The twelve base combinations of Porter and Duff's image compositing concept and the result of the combinations (Pedersen, 2013).

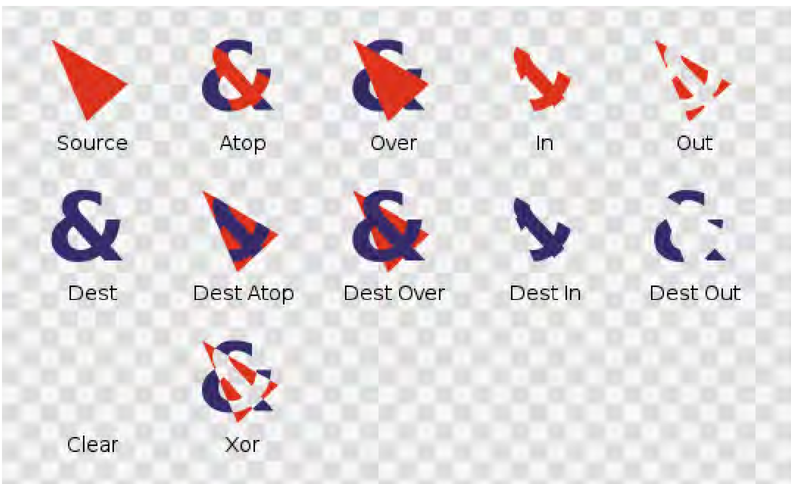


Figure 2.2: The twelve base combinations of Porter and Duff's image compositing concept shown visually (Pedersen, 2013).

Even though the concept of Porter and Duff is not mainly intended for blending, there is a layer to this way of working which they mention is associated with a *blend mode*. This mode can be used to modify what is shown in the area where both images are visible. As an example, they speak of the 'Color Dodge' blend mode which computes a mixed result inline with a blending formula. Unlike the 'Over' operation shown in figure 2.2, the output of the overlapping area becomes a mix of the two chosen images. The result of such mix can be seen in figure 2.3 (Pedersen, 2013).

Figure 2.3: Figures showing how Porter and Duff meant that the combined area of two images can appear (Pedersen, 2013).

2.3 Related Work

This section will give an overview of related installations or entities that has been used in multisensory environments or in another type of relatable environment and the type of conclusions that has been drawn from the different studies.

2.3.1 Colour Organ and Synesthesia

The Color Organ originates from the time of the Enlightenment around the 16th century, where the idea behind it was the thought of having a connection between lights and sound, performing coloured light through an instrument as done in music (Betancourt, 2015). During this time, Athanasius Kircher who was a Jesuit polymath, discussed colour and sound in regards to their placement in a system of, what he called, "celestial harmony" (Betancourt, 2015). This idea served as a base for the later 19th centuries inventors which took the idea further in their own attempt to create their own Colour Organ. Mary Hallock-Greenewalt was one of the inventor who aspired to create her own Color Organ as an attempt to make an art form equivalent to the one of music (McLean, 2009). Athanasius Kircher claimed in earlier centuries there to be an existence of a direct link between colour and music (Betancourt, 2015). For further reading in the subject see *Musurgia Universalis, 1650* by Athanasius Kircher (Kircher, 1650).

Seeing connections between colours and music or connections between music and shapes can be part of an additional sensory experience connected to an impression or thought, an entity also widely called *synesthesia*. Danielsson (2020) means that the estimated percentage of people who have this kind of additional experience is about 4 % of the population. Synesthesia is rarely experiences in the same way by individuals and as such, the experience can vary from experiencing connections between colours, music, shapes, tastes and scents. The most common nature of the experiences is the connection between colours and sequential linguistic units, such as numbers, letters and weekdays (Danielsson, 2020).

2.3.2 The Interactive Ball

The interactive ball is an artefact created by van Delden et al. (2019) for people with PIMD as part of a exploratory study to measure the effect of the interaction with the artefact. The authors looked at the individuals alertness, affective behaviour and movement and whether the interactive ball could be used as a way to increase or improve these areas.

The ball was designed to emit light, wiggle, move from right to left and make different sounds as a response to gross motor movement, the individual's focus of attention and their vocalisation. These different types of outputs where intended to encourage the user to engage in active interaction, e.g using different kinds of non-verbal interaction to increase or decrease visual/auditory stimulation. The authors recognise that one issue within interactive installations for people with PIMD is that many of these installations rely on micro-switch interaction (ON and OFF) instead of using a more dynamic interactive system. One of their goals with the interactive ball was to use gradual forms of input and output in order to create a truly interactive system. This was echoed in another study done by Luhtala, Kymäläinen, and Plomp (2011), where they concluded that only having micro-switch interaction limited the exploration and playfulness of the musical instrument. At the same time, they stress the importance of not designing a too challenging instrument in order to minimize the risk of the user experiencing a feeling of failure.

Nine individuals with PIMD participated in the study of van Delden et al. (2019). A single case design approach was chosen, including both inter-case replication as well as within-case replication, which spanned over 7 days. The tools they used to gather data included observation and video recording of the participants as well as semi-structured interviews with accompanying staff members. This methodology was used in accordance to at the time's ruling practice and in consideration to the wide difference between participants within the target group.

The study showed that only some participants showed a positive effect as a result of interacting with the ball. The explanation that van Delden et al. (2019) gives to this is that the heterogeneity of the group was big; some individuals might benefit from it and show a positive response towards moving more, while restless persons may not view the ball's incitement to trigger movement as something positive. However, they stress that the installation may still provide a source of entertainment and improve alertness, affective behaviour and movement for some of their users, and would be more beneficial than other forms of passive entertainment, such as TVs.

As mentioned in this article, switch-like interactions are commonly used for installations in multisensory environments. An aspect of this, is that they allow for less exploration and playfulness compared to more dynamic interactions. Having a target group that is heterogeneous as in the case of people with PIMD, where there can be a big difference in cognitive and physical abilities between individuals, means that some people can have a harder time performing certain interactions than others. This in turn can lead to a disparity in experience, where some people may find an interaction adequately challenging and thus enjoyable, while others may find it too easy or too hard which can result in a negative user experience. This is also a factor which should be considered for this type of installations, the need to design something which is not too challenging in order to not let the user experience feelings of failure when interacting with it. These factors are important to consider when designing an installation for people with ID.

Figure 2.4: The Interactive Ball created by van Delden et al. (2019), with variations in aesthetics depending on the type of colour you choose.

2.3.3 Design Artefacts for Tangible Interaction

The purpose of the study conducted by Caltenco et al. (2012) was to open up for dialogue and ideation within the field of haptic and audio interaction and to contribute to a more interactive multisensory environment. The study was part of a bigger project called SID, where the purpose was to enhance the engagement of children with profound development disability in the multisensory environment by exploring ways to use continuous coupling interaction involving tactile and proprioceptive senses. Proprioceptive senses which involve positioning and movement of limbs and trunk (Proske & Gandevia, 2012).

The artefacts were created in such way that they would be interactive, but yet easy enough to replicate and alter in accordance with the children's actions. This was necessary due to the children not being able to participate in the interplay, which required pretending, abstract thinking and continual attention. Methods that included mock-ups or Wizard of Oz were ruled out due to these limitations in interplay (Caltenco et al., 2012).

One of their creations was the LivelyButton(see fig. 2.5), which is a box with two metal spirals located at the top-side of the box below a semi-transparent fabric. LivelyButton reacts to the touch of the user and starts to spin the two spirals accompanied by the sound of the motor and the vibrations that arises as a result. Its purpose is to explore spatial co-locatedness.

Figure 2.5: Here you can see how the LivelyButton looks like on the inside, showing the two metal spirals and the wires. On the right showing how one of the users interacted with it (Caltenco et al., 2012).

Another artefact which is described is the LivelyForm (see fig. 2.6) which is a design that Caltenco et al. (2012) describes as a creation which points beyond the common multisensory environment practice in the aspect that it introduces a moving object. It is constructed as a worm-like elongated form which can stretch and curl. The thought behind this artefact was to investigate if it can promote body movement in the children interacting with it. An observation made was that the children tended to grab the object rather than in its intended way of alternating between touching and looking. As a result the artefact was altered to instead react on movement rather than touch.

Figure 2.6: In the left picture you can see the inner parts of LivelyForms and how it was built, while the right image portrays a user interacting with the finished prototype (Caltenco et al., 2012).

The third design they present is the ActiveCurtain (see figure 2.7b), which is a soft screen which responds to the touch of the user by emitting colours and auditory feedback where it is being touched. The artefact uses a Microsoft Kinect sensor behind the curtain to detect the location and the depth of the touch. Depending on the depth of the touch, the projected colour changes together with the intensity.

Figure 2.7: To the left (a) you see the MalleablePillow and how colours are emitted upon touch. To the right (b) you see how the Active curtain responds to the users finger touching it (Caltenco et al., 2012).

Lastly, the MalleablePillow (see figure 2.7a)is a construct made out of a semi-transparent fabric and grouped LEDs connected to microphones which picks up the sound of kneading, where a higher kneading sound results in a more intense colour emission around the kneaded area. The fundamental thought of this design was to explore co-located coupling of actions and effects which are connected to the user when they use their body (Caltenco et al., 2012).

Caltenco et al. (2012) mentions that with help of observations of the children interacting with the artefact and the interpretations of their action by the institutions pedagogical staff, an evolution of the artefacts was possible.

Combining different kinds of materials which the target group is allowed to try is what Caltenco et al. (2012) has shown can be useful when exploring and working on ideas. As people with profound developmental disability can have difficulties with abstract interplay and thinking, it can be useful to design installations in such way that the artefacts are easy to alter in order to adjust the product in accordance to its use. Involving caretakers can also be a necessity when trying to evaluate the interaction of this target group, as it can be more difficult to interpret their thoughts and feelings as an outside observer.

2.3.4 Polly World

Polly world is the fourth generation of interactive multi-sensorial environment which has been developed during a long-term project and the result of the three previously created generations (Cappelen & Andersson, 2016). The project focuses on the designed qualities and puts emphasis on the multi-sensorial and musical interaction design and presents how these have been designed in order to make them more health promoting.

The Polly world described by Cappelen and Andersson (2016) consists of one wired and three wireless textile interactive objects which serves the purpose to give rise to positive emotions by combining musical and sensorial interactions. These objects combine lights, music and sensorial stimulating surfaces to different degrees. By using RFID-tags attached to different cards, the user can interact with the environment and change attributes such as light, music and visual graphics. This kind of possible variation was included in order to give the users the possibility to manipulate their environment to their liking and independently decide what to interact with. Cappelen and Andersson (2016) stresses the importance of creating an environment which can be customized to the users preferences in order to evoke positive emotions, this includes familiar objects, music and digital entities. Having customizable environments and installations can help users to personalize their interaction and experience to a greater extent, which Cappelen and Andersson (2016) mentions can result in connecting diverse users and to create an empowering and healing social space.

3
Theory

In this chapter, concepts important to the projects realization and development in relation to the theoretical background of the practical implementation will be brought up. This chapter will also include the theoretical aspects of design practices which will be of more importance in this project.

3.1 Mapping

Mapping can be described as the relationship between the elements of two entities, entities which do not necessarily need to be two separate objects but can be different parts of the same object (Norman, 2013). The concept of mapping has proven to be important for the design and layout of different artefacts, particularly in regards of their controls and displays. Norman (2013) mentions that applying the concept of mapping in an accurate manner can simplify the understanding and determination of an entities usage, where the use of spatial correspondence of layout and controls is a cause of this effect. He further argues that in order to make it easier to learn the relationship between the result of an action and the control causing it, incorporating an understandable mapping between the elements of control, action and intended result is a proper approach.

Natural mapping is an aspect of mapping, which gives the user an immediate understanding of the intended result. This type of mapping makes use of spatial analogies to let the user understand how the controls should be used for a certain outcome (Norman, 2013). Norman (2013) writes about three levels of mapping, ranking them in effectiveness for memory aids, from most effective to least: *Best-mapping* is explained as the mapping where the controls are mounted directly on what it should control. *Second-best mapping* are the controls which are put as close as possible to the item to control. The *third-best mapping* is when the controls are placed in the same spatial layout as the object to control. Norman (2013) means that the first and secondly explained type of mapping are the most clear and unambiguous ones.

Goudeseune (2002) talks about mapping in relation to instruments and argue that there are three main questions which one can pose when it comes to this kind of mapping: *From what? to what?* and *by what?*. The two first questions are answered by the connection between a user's inputted gestures and the outputted sound that is a direct result of this interaction. The third question is explained in the context of what is required in order to send input to the instrument, talked about as controller, which has a distinct definition than the traditional 'TV controller'. Here it is defined as the entire interface of the instrument or the set of commands which are available to the instrumentalist. Goudeseune (2002) further writes about a mapping which she means is specifically useful in musical contexts, a mapping which helps the user associate certain kind of input values with certain kind of output values. If the user does A the instrument should output B. Hunt and Wanderley (2002) describes three basic strategies for mapping between two parameters in music instruments; the first one being a one-to-one mapping, where one parameter is connected to one other triggering parameter; the second one is a many-to-one mapping, which works in the way that several parameters are connected and triggered by a single parameter. Lastly, the third strategy is the one-to-many mapping, which is when one parameter is connected to many other parameters and can be triggered by these. Thinking about instrumental mapping in the form of these basic principles can aid in the understanding of the relationship between the different parameters of an instrument.

Understanding mappings and their relations is a mental process which involves using the human cognition, Hessels-Schlatter (2002) mentions the work of Arthur R. Jensen in 1969 and 1970 that showed that people with moderate and severe mental retardation have a limited ability to reason and can, as such, not reason further than to a concrete level. Lifshitz, Weiss, Tzuriel, and Tzemach (2011) also mentions that people with ID can have reasoning difficulties in regards of understanding abstract relations between two entities or objects. This can be supported by the report written by Goldbart and Caton (2010), as they write that people with profound intellectual impairment can be aided in understanding that their actions have consequences, this can be done by creating causality in their activities i.e "cause and effect".

3.2 Tangible Interaction

In order to understand the notion of Tangible interaction, an understanding for what relation a tangible object can have to digital systems is a starting point. Van Den Hoven et al. (2007) explains that the basic knowledge which tangible interaction is build upon originates from the human-computer interaction. Ullmer and Ishii (2000) further describes a tangible user interface as something physical which gives form to digital information, that through the physical artefact is both a representation and a control for the computational media. They further mention that a tangible user interface couples a physical representation with a digital representation, where a physical representation can be a manipulable object and an examples of a digital representation can be audio or graphics. Input devices can be time-multiplex or space-multiplex, where the first term concerns the use of a single device to control different functions at different points in time, while the second term concerns the use of different devices occupying a separate space, each having a particular function (Fitzmaurice & Buxton, 1997a). Tangible interaction per se focuses more on the research of a whole-body interaction, interactive spaces and gestures as an input method. Focusing more on the interaction and how it is experienced by the user rather than the visible interface and even though it can combine graphical and tangible elements its emphasis still lays in the quality of interaction with the system (Shaer & Hornecker, 2010).

Another concept which is related to tangible user interfaces and is talked about in parallel is the graspable user interface, it is explained as specialised input devices that can serve as interface widgets, which allow spatial and physical manipulation (Fitzmaurice & Buxton, 1997b). One factor which Fitzmaurice and Buxton (1997b) points out to be important for graspable interfaces is the emphasis on the usage of more than a single input device when interacting. For a greater understanding, a comparison between a graspable UI and a traditional graphical user interface was made, and thus, when comparing the two UIs, one significant difference can be seen (Fitzmaurice & Buxton, 1997b) in figure 3.2. Here, the acquiring of a logical device is defined as the use of the widgets of an interface e.g buttons and scrollbars, which is a phase which does not exist for graspable UIs. As such, the physical device is directly connected to the logical device.

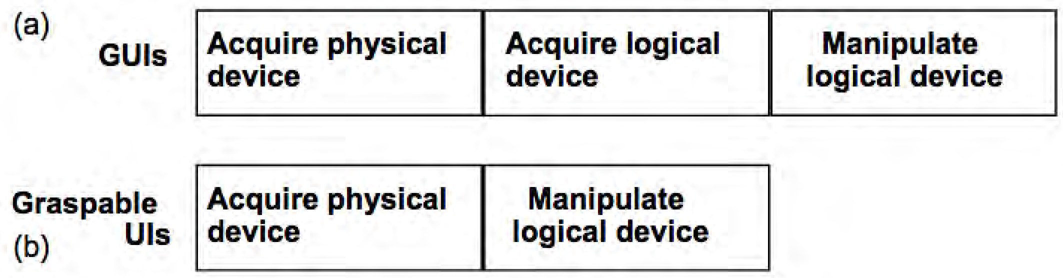


Figure 3.1: Fitzmaurice and Buxton (1997a)'s interaction phases of GUIs (a) and graspable UIs (b). While GUIs require the acquisition of knowledge about buttons and scrollbars (mentioned in the table as *acquire logical device*), graspable UIs does not.

3.2.1 Phenomenological and Social Framework of Tangible Interaction

Hornecker and Buur (2006)'s framework grew forth from the motivation to create a tangible interaction framework which highlights the phenomenological and social perspectives. In contrast to frameworks which focus on terms, categorization and charactization, which more frequently take a structural approach rather than the approach of the interactive experience of the human (Hornecker & Buur, 2006). The framework presented by Hornecker and Buur (2006) contains four main pillars, which they refer to as "themes" and mean offer different perspectives to tangible interaction which interrelate and are thus not mutually exclusive of each other. The four themes are the following:

Tangible manipulation which is described as the different tactile qualities of a material and its representation which also tend to be physically manipulated.

Spatial interaction is the fact that interaction is interrelated to real space and as such, the interaction is possible with help of movement in the space.

Embodied facilitation highlights the arrangement of objects and space is done and how it directs and affects emerging group behaviour.

Expressive representation is the focus of the material and digital representation applied to the tangible interactive system, the readability/ clarity and the expressiveness of it.

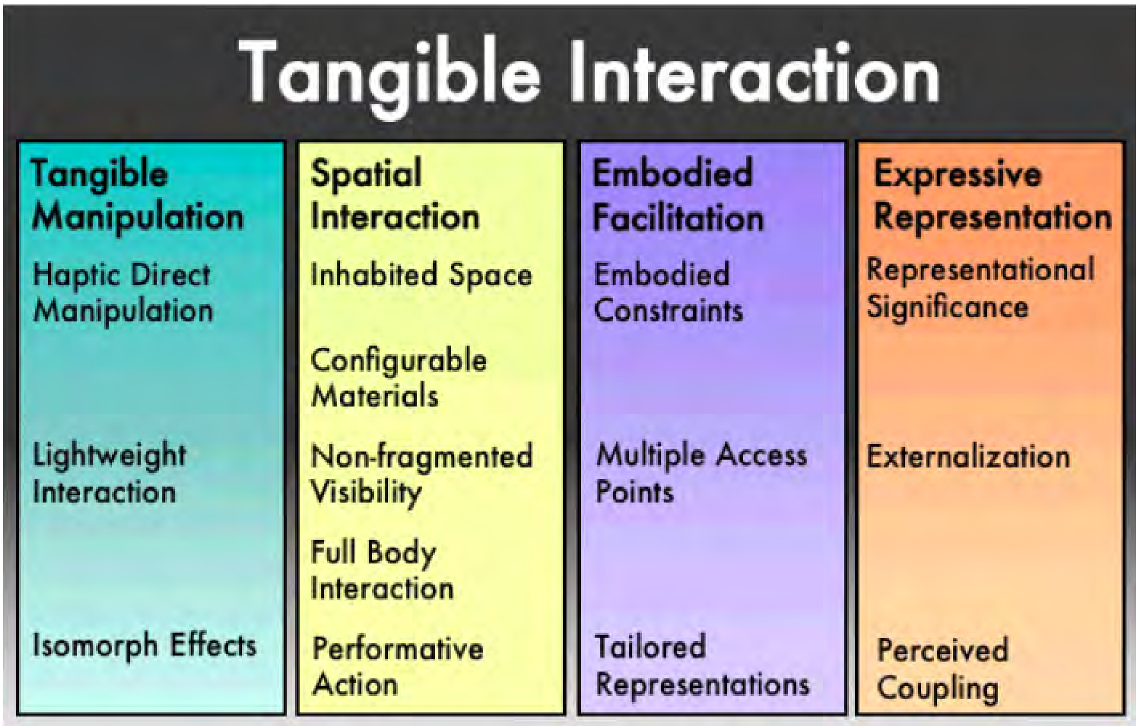


Figure 3.2: As presented by Hornecker and Buur (2006), tangible interaction can be divided into four categories: *tangible manipulation, spatial interaction, embodied facilitation* and *expressive representation.* Each category having its respective subcategories.

As shown in figure 3.2, all the different themes have sub-concepts as part of them. These themes and concepts can be used to highlight different perspectives of the same object and help guide design (Hornecker & Buur, 2006).

3.2.1.1 Tangible Manipulation

In this theme Hornecker and Buur (2006) talkes about *haptic direct manipulation, lightweight interaction* and *isomorph effects*. *Haptic direct manipulation* is the concept of direct manipulating an object, an object which is the interface, the interaction object and interaction device all at once. It touches upon the occurrence of manipulation of the interaction object, gets tactile contact and then feels the haptic feedback and the materials qualities Hornecker and Buur (2006). The *lightweight interaction* is a concept which puts emphasis on constant feedback. Allowing the users to test and express themselves while moving forward in small steps. Lastly, *isomorph effects* is the concept which touches upon the tangible objects legibility, e.g having it close by, having it visible nearby or what shape it has. Factors which preserve the motor or manual action of the user.

3.2.1.2 Spatial Interaction

The second theme of Hornecker and Buur (2006) is the *spatial interaction*. Here, the first concept *inhabited space* speaks of the phenomenon of real space always being *inhabited* and interrelated to a context,having a meaning. A meaning given by objects and their positioning in relation to the own body. This also involves the second concept of *configurable materials*, which is the meaningful re-arrangement of more significant objects in the space in order to explore and control the environment. Moving on to the third concept, *non-fragmented visibility*. This is the reciprocal situation where seeing implies being seen, without any fracture in the picture when changing line of sight. On the other hand *full body interaction* is the potential of using the entire body to interact with the system in the space, using large, expressive and skilled body movements. Movements which takes communicative and performative form or function, performative being defined as communicating the "how" something is done (Hornecker & Buur, 2006).

3.2.1.3 Embodied Facilitation

The first concept in this theme addresses the *embodied constraints*, which is the size, location or form which an object can have. Qualities which are part of limiting or easing activities with their implicit suggestions. *Multiple access points* is about how to access and manipulate relevant points of an object, the *multiple* points are relevant in order to distribute control and counteract a single user situation. These points involve the resources for interaction, observation and accessing which the objects has, both in terms of restrictions and privileges. The last concept, *tailored representations* is as it sounds, representations which are tailored for the user group in order to invite to interact, engage and create an emotional link. Taking into consideration the users skills and experience in order to be able to fit their abilities (Hornecker & Buur, 2006).

3.2.1.4 Expressive Representations

Representational significance emphasises the physical tokens and their embodiment of the core aspects of the system and the eligibility which comes with it. How users perceive the interrelation between the physical and digital representation. This comes close to the *externalisation* concept, which concerns individuals externalizing and sharing their thinking. How this, among other things, aids the cognition, helps create shared references, both internally and explicitly, augment talk and helps remember traces. Once again, the next concept is close in domain. *Perceived coupling* addresses how the user perceives the connection between the digital and the physical, likewise, if the outcome is perceived as an effect of the action. Perceived coupling can help the user understand the systems reactions and enhance the experience of the system and object being hybrid (Hornecker & Buur, 2006).

3.3 Design Theory

This part of the theory will cover some design practices that are relevant to this thesis.

3.3.1 Accessibility

Accessibility has been defined by Microsoft (2016) as an attribute which can be combined with different design methods to create experiences that are usable and open to everyone. Depending on the situation, different accessibility standards have been defined; in the context of transportation it can be of relevance to talk about the robustness and perception of accessibility for a design (van Wee, 2016), while in web design it is more important to look at contrast, size, location and adjustment of volume, etc. (Zahra, 2019). Making a product more accessible means addressing one or more of these different standards.

One way to address these standards in the context of digital interfaces is to make them multimodal. Obrenovic et al. (2007) views the interaction between the system and the user as a communication channel. This channel can be affected and influence by different constraints, where Obrenovic et al. (2007) defined two of these as user and environmental constraints (see figure 3.3). User constraints consists of features, states and preferences that the user may have. A user feature is described as a long-term ability of a user to exploit some aspects of a design and includes the user's different abilities and disabilities. A user state, which is divided into emotional and cognitive categories, is a user's temporary ability to interact with a design. User preference is the internal motivation, the desire, of a user to engage in an interaction. Environmental constraints are in a similar way divided into three categories: device constraint, environment constraint and social context. Device constraint is the limitation that one or more characteristics of a device can induce. As an example, Obrenovic et al. (2007) mentions that a computer mouse is limited to a 2D space and a specific resolution, which puts constraints on how it can be used. Environment constraint is the limitations that the environment can have on the interaction, where someone being in a noisy environment will have a reduced hearing. Finally, the social context is the social situation where the interaction takes place.

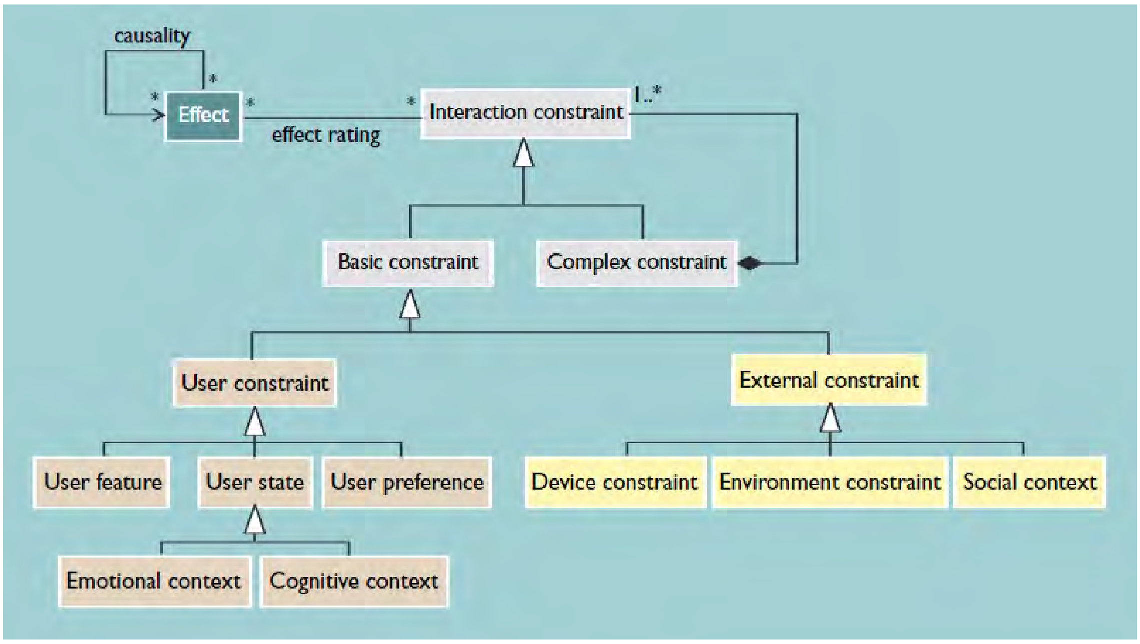


Figure 3.3: A simplified model of the different interaction constraints as presented by Obrenovic et al. (2007).

The framework presented by Obrenovic et al. (2007) can be used in order to find common denominators in constraints between different users and, by addressing these, improve the experience for multiple users. By making multimodal interactions, designer can increase the accessibility of a design and open up the interaction for a more diverse audience. Two design methods that strives to increase the accessibility includes inclusive design and universal design.

3.3.1.1 Inclusive Design

When designing a product or environment, the designer will use their own experience, knowledge and opinions during the design process. Although this is unavoidable to a degree, it can become problematic in situations where the designer is designing for someone other than themselves; the abilities and the biases of the designer will result in a product designed for similar individuals, that is, individuals of a specific sex, ethnicity, education, language, age and physical ability (Microsoft, 2016). Inclusive design is a method that can be applied by designers in order to make a product or experience applicable to a wider and more diverse audience.

A common misconception when it comes to inclusive design is that the purpose of the method is to include everyone in the final product. As described by Microsoft (2016, p. 11): "Designing inclusively doesn't mean you're making one thing for all people. You're designing a diversity of ways for everyone to participate in an experience with a sense of belonging". As such, inclusive design focuses on creating ways in which everyone can participate in the experience. An example includes the addition of subtitles to videos in order to allow deaf people becoming a part of the experience.

As described by Microsoft (2016), inclusive design consist of three principles: *recognize exclusion*, *learn from diversity* and *solve for one, extend to many.* Recognize exclusion is about knowing why and how individuals may be excluded from an experience. This includes identifying points in the interaction where a mismatch between user and system occurs and also how to limit these mismatches. Exclusion can also be limited temporally or to a specific situation; having your vision reduced due to bright sunlight is considered to be a temporal exclusion, while only have one arm available when carrying groceries is considered to be situational. As a designer it is important to know these types of exclusions and how to design for them. Learning from Diversity means that designers should pay attention to how their design is being used and what kind of adaptations the user undergo, if any. This allows the designer to not only find barriers with their design but also find the underlying motivations that are common between all users. Solve for one, extend to many is the idea that a design solution targeted for one individual or one type of users can benefit more than those individuals. As an example, Microsoft (2016) mentions the example that a design which benefits blind drivers may be beneficial for other people as well.

3.3.1.2 Universal Design

Universal design is similar to inclusive design and is often mentioned in the same context, however there are some important differences between them. While inclusive design is a newer concept which originates from the digital realm, universal design has its roots in the architectural field. One major difference between these fields is that digital technology allows designers to create a customize experiences for each user, while the design of buildings and environments often requires one design that is accessible to everyone. The Inclusive Design Research Centre (OCAD, 2013) summarizes this as one-size-fits-one versus one-size-fits-all. Whatever approach the designer chooses, both inclusive and universal design tries to increase the accessibility of a product or environment.

Story (1998) identified several aspects that are important to consider when designing for universality. These include: *equitable use, flexibility in use, simple and intuitive use, perceptible information, tolerance for error, low physical effort* and *size and space for approach and use.*

Equitable Use - The design should be useful and accessible to people with diverse abilities: it should appeal to all individuals, have the same interaction when possible and equivalent interaction when not, and the designer should avoid to stigmatize or segregate a group of individuals.

Flexibility in Use - The design should allow for customization of individual preferences and abilities: the user should have multiple choices of methods to use, be able to use left or right hand equally, and have a design which adopts to the precision, accuracy and pace of the user.

Simple and Intuitive Use - The design should be easy to understand and interact with, independent of the previous knowledge and experiences of the user: be consistent with expectations, avoid unnecessary complexity, provide clear feedback, arrange information related to its importance and address a wide range of language and literacy skills.

Perceptible Information - The design should be able to communicate all of the necessary information effectively to the user, regardless of their sensory abilities: it should support different devices used by individuals with sensory limitations, maximize readability for important information and present this information in redundant ways (tactile, visual and auditory).

Tolerance for Error - The design strives to minimize hazards and give reasonable responses to unintended actions or incorrect use: elements should be arranged as to reduce errors and misuse, hazardous elements should be eliminated or shielded, appropriate warnings should be provided together with fail-safe features, and unconscious interaction should be discourage when attention is important.

Low Physical Effort - The design should be ergonomic and minimize fatigue: repetitive actions and sustained physical effort should be avoided, the user should not be forced to change body position or use unreasonable forces in order to interact with the system.

Size and Space for Approach and Use - The design should facilitate appropriate use, regardless of the user's size, posture and mobility: the user should be able to have a clear sight to - and be able to reach - all important elements from both a sitting and standing position, and have sufficient space in order to use assistance from external devices or personnel.

3.4 User-centered Design

The aim of user-centered design (UCD) is to explore how 'definition of use through design' and 'definition of use through use' can be combined in order to anticipate the eventual use of a product (Redström, 2008). This of often done by having two different groups of people from different domains of expertise, usually designers and people representing the targeted user group. The goal of UCD can in some cases be to carry out user tests in order to find out if a certain products is easy to understand and use, while in other situations the goal could be to find out what the eventual use *could* be like. This is an important part of interaction design, as imagining how a person may interact with an experience can be possible to a degree, but imagining their emotional context and what give them joy or frustrates them, is not (Microsoft, 2016). As such, learning about the users and how they interact with a design is vital for its success.

User-centered design is sometimes used indistinguishably with human-centered design (HCD). However, as mentioned by (International Organization for Standardization, 2019). HCD involves the stakeholders in the process to a greater extent, while UCD focuses more on the user group in question. Although both approaches vary in their focus, they still utilize the broader design process of iteration (International

Organization for Standardization, 2019; Norman, 2013). As mentioned by Hartson and Pyla (2012), the general process of interaction design follows a four-activity chain: analyze, design, implement and evaluate. The process begins with the analysis, where designers try to get an understanding of the needs and requirements of the users. Once this has been established, the creating of design concepts can start. The concepts will then be realized in some sort of prototype, which can consists of anything between drawings on a paper to an intractable application. The prototype should then be tested and evaluated on the target group in order to find out how well it fulfill their needs and requirements. The requirements are then updated in accordance to the evaluation and the process repeats. As illustrated in figure 3.4, this process often includes iterating on each step and sometimes go back to the previous phase before continuing on to the next one.

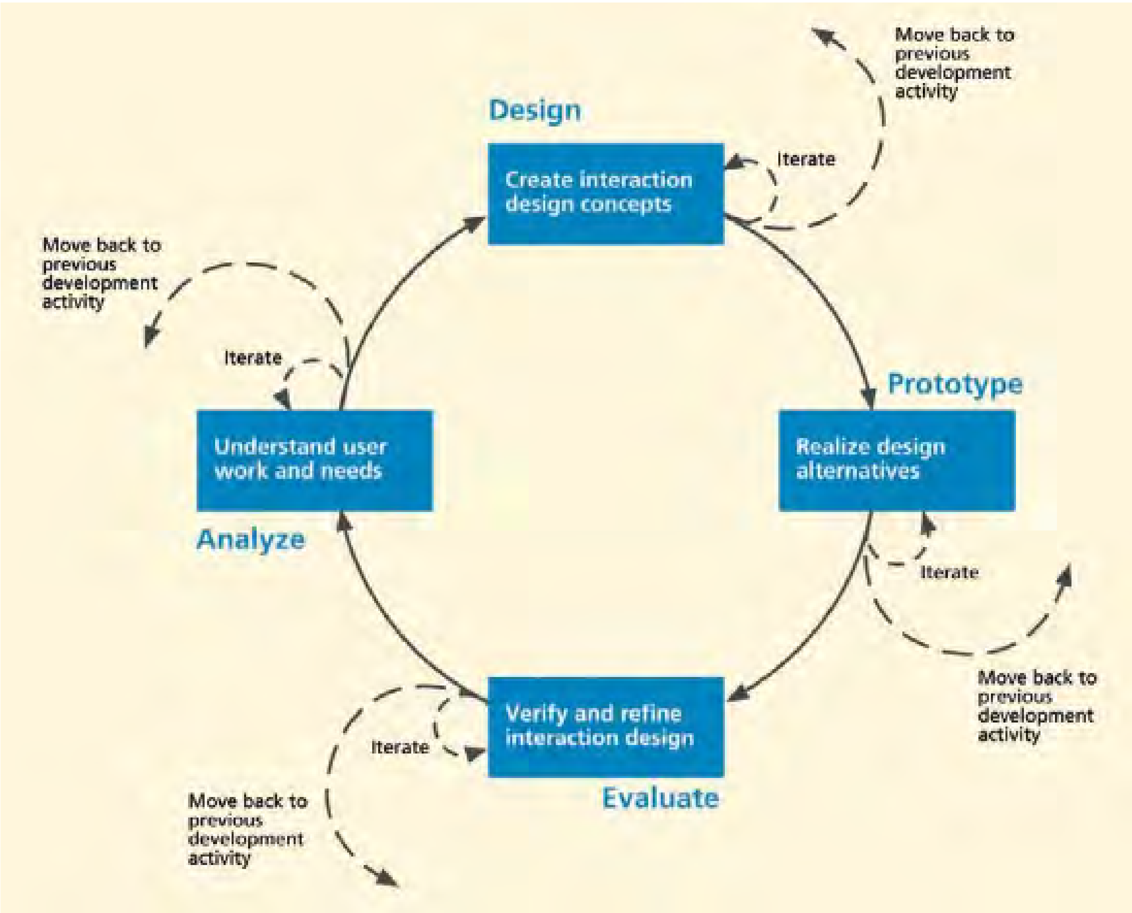


Figure 3.4: The UX cycle as presented by Hartson and Pyla (2012). The process begins with analyze and proceeds in clockwise order, with each step allowing for iteration and moving back to the previous activity.

4
Methodology

There are several different methods within interaction design which can be used during design processes, each method having its pros and cons. In this chapter we account for some relevant methods which can be used in order to meet the set goal of the intended design process.

4.1 Research Methods

This section will cover some methods that can be relevant to use when gathering data about users, interactions and the feedback of artifacts, in the context of designing a multisensory installation for people with PIMD.

4.1.1 Pre-study

Whatever kind of product or environment that is being design, the process should always start with establishing requirements. These requirements can sometimes already be predefined by one of the stakeholders, or they may need to be established from scratch; whatever the situation may be, the initial phase of a project should evaluate and discuss the users' needs, expectations, aspirations and requirements in order to get a better picture of who the users are. This becomes important as every individual have their own view and theories of how the world works, which affects the way they interact and experience their environment (Wadsworth, 2011). In order to evaluate the users' needs and requirements, the designers will have to gather knowledge about the users' abilities, goals and routines, as well as get an understanding for the conditions of which the product will be used in and what constraints that includes. This is necessary in order to create a product or environment that is capable of supporting the user in reaching their goal (Preece, Rogers, & Sharp, 2015).

The pre-study, or user research as it is sometimes referred to, consists of multiple steps. Although the number and name of these steps differs between authors (Preece et al., 2015; Hartson & Pyla, 2012)), three recurring ones are: data gathering, data analysis and requirement extraction. The gathering of data can be done by applying methods such as observation, interviews and questionnaires. While one of these methods can provide useful information, is it often of good practise to combine multiple of data gathering techniques as they all have their own pros and cons (Preece et al., 2015). The data can then be analyzed and evaluated in order to get a better understanding of the users. This process is not discrete with a specific end date; it is an iterative process which can proceed throughout the entire design process depending on how the interaction between users, stakeholders and the design unfolds.

4.1.2 Heuristic Evaluation

Heuristic evaluation is an informal usability method where the aim is to asses how well a design lives up to the standards (Hanington & Martin, 2012). This method distinguishes itself from usability test in that no real users are involved in the test. Instead, the designers recruit experts and novices alike from within the team. These individuals then asses the interface and summarize their finding into one single usability report. This report can then provide the design team with manageable and meaningful principles to work from, instead of having them rely on intuition. Although the heuristic evaluation method seldom gives new perspectives or design solutions, it can be useful for identifying critical errors early in the design process and help to make the design ready for user testing (Hanington & Martin, 2012).

4.1.3 Usability Test

Usability test is an evaluation method which lets designers evaluate how well their design fulfill the needs and requirements of the users. The method is usually performed in a controlled environment where designers have the ability to control different parameters and observe users' experience with a product (Preece et al., 2015).

Usability tests are centered around scenarios and tasks. Scenarios helps to contextualize the task and provide additional information to the user which may be needed in order to complete a task (Hanington & Martin, 2012). The tasks in turn are used to evaluate specific features of the design and can range from anything between navigating in menus to reading typefaces or finding specific information (Preece et al., 2015).

The data gathered from a usability test can come from measuring the time it takes for users to perform a task, count the number of errors made, how many users complete or fail a specific task etc. (Preece et al., 2015). One of the more common methods to combine with usability tests is the Think-Aloud technique (Hanington & Martin, 2012). This method requires the user to speak out the thought and feelings they experience while interacting with the product. The designers can then take note of different things that may be of interest for the design. Hanington and Martin (2012) mentions some of the things designers should look for:

1. Does the user fail to complete a task within a reasonable amount of time?
2. Do they give up without completing the task?
3. Do they complete the task in an unintended way?
4. Express frustration, surprise or other emotions when interacting?
5. Do they complain that something is not working or doesn't make sense?

6. Do they give suggestions for improvements?

Some important things to pay attention to is that when practicing usability tests, you as a designer should make sure that you have at least 3 users to test on (Benyon, Turner, & Turner, 2005) and that developers and potential stakeholders are included together with the targeted user group in order to get the perspective of all significant parties (Hanington & Martin, 2012).

4.1.4 Pilot Study

A pilot study can be said to be a mini-format of the main study. The purpose of it is to test if a proposed method is viable before executing it (Preece et al., 2015) Due to the unpredictability of users and user tests, it is of good practice to test methods and what results they will yield before doing them on a bigger scale. This includes everything from testing equipment to make sure it works properly, going through the data gathering methods in order to make sure that the questions are well formulated, and to verify that the result has the expected format. It is important to note, however, that the users that are participating in the pilot study cannot participate in the main study later, as these individuals will have more experience and knowledge about the study and thus can distort the results (Preece et al., 2015),

4.1.5 Observation

Observation is an exploratory design method where designers investigates an artifact, behaviour, environment, event or interaction through systematically observing and taking notes. Observations can be divided into different levels of formality depending how they are executed and on what types of tools are being used (Hanington & Martin, 2012). Informal observations allows the designers to be more open-minded and flexible and is usually conducted during the early stages of the design process in order to get an understanding for the users' context and goals (Preece et al., 2015). Even though informal observation allows for a more flexible and less strict type of observation, the data gathering should still be done systematically through well-documented notes, sketches, photographs or videos (Hanington & Martin, 2012). Formal observations on the other hand is more structured and utilizes the coding of behaviour and events through worksheets and checklists (Hanington & Martin, 2012). This type of observation is best suited when environmental and behavioural factors are well defined (Hanington & Martin, 2012) and when evaluating whether or not the prototype supports the goals of the users (Preece et al., 2015).

Observations can involve the designer to a greater or lesser extent, ranging from passive observer to active participant (Wadsworth, 2011). At the passive end of the spectrum, the designer is observing from afar while avoiding any direct contact with the person being observed. In the active end, the designer instead becomes a part of the community or culture and actively engages with the user group. The observation can also be done directly or indirectly (Preece et al., 2015), where an example of the latter includes going through video footage of passed events. The setting in which the observation is taking place can also differ, where Preece et al. (2015) mentions two different conditions; the study can either be conducted in a laboratory settings where the designers have control over various parameters, or in a more ordinary setting, which is often referred to as "in the wild".

4.1.5.1 Fly-on-the-wall Observation

A fly-on-the-wall observation is a type of observation which allows the researches to gather information in an unobtrusive way, this is done by looking and listening without directly interfering or participating in what is being observed, be it behaviours, people or interactions(Hanington & Martin, 2012). This observation method differs from other observations, like a participatory observation, as it intentionally removes the direct involvement of the researchers on what is being studied. It aims to minimize possible biases or behavioural influences which a researcher can spur by being engaged, something which on the other hand, can lead to a lowered possibility for the researcher to connect emphatically with the user and look deeper into participants motivations behind behaviours.

Even though this kind of observation is usually conducted in a flexible manner without any predetermined criteria to categorize or code observations, it can still be useful with some kinds of framework or worksheet as a base (Hanington & Martin, 2012). To this, Hanington and Martin (2012) mentions that there are two types of approaches, the *recognized outsider* and the *secret outsider*, two observation methods which are conducted a bit differently. *Recognized outsider* is a method which implies that the researcher has made himself/herself known as an observer to the person being observed. A disadvantage with this method is the possibility of changed behaviour as the user at some degree is aware of the observation, despite the effort of keeping a distance. *Secret outsider* is observing at a distant, removing them from the participants, minimizing the presence but also reducing the possibility to capture emotional depth and individual nuances.

4.1.5.2 Design Ethnography

Ethnography is a method used for exploratory user research and when it comes to the intent of it within design, Anna Bowling in (Hanington & Martin, 2012, p. 60) explains design ethnography as:

> “The study of people in their natural settings; a descriptive account of social life and culture in a defined social system, based on qualitative methods (e.g., detailed observations, unstructured interviews, analysis of documents).

Hanington and Martin (2012) means that design ethnography is a broad approach which includes many research methods with a focus in understanding the users and the domain, in an emphatic and comprehensive way. It focuses on the users lives, their language and context of their artefacts and behaviours. Methods used in design ethnography are mainly qualitative and uses patterns and themes from the research phase, summarizing them to become design implications or guidelines, which can later be used in the concept development (Hanington & Martin, 2012).

4.1.6 Interviews

Hanington and Martin (2012) explains interviews as a research method to collect firsthand accounts of experiences, attitudes, opinions and perceptions and that interviews can benefit from being done in person as body language and personal expression can be better recognized (Hanington & Martin, 2012). There are mainly three types of interviews, there are structured, unstructured and semi-structured. Structured interviews are created in such way that they have predetermined questions which the interviewer sticks to and goes through with every participant, as such, creating a more standardized study (Preece et al., 2015). The unstructured interviews are more flexible and are like a conversation around a topic, at times with some guiding topics by the interviewer which are aimed to be addressed during the interview (Hanington & Martin, 2012; Preece et al., 2015). Lastly, a semi-structured interview usually combines parts of a structured interview and an unstructured interview, having both open-ended questions but some closed questions as well (Preece et al., 2015). It tends to make use of a script to make sure the same topics are covered during the different sessions and works as such that a topic, or question is initiated and then the interviewee is allowed to talk and build on the answer until there is no more relevant information for the main topic (Preece et al., 2015). Hanington and Martin (2012) means that interviews are one part of a research strategy and are usually complemented with another method in order to further humanize and verify the data, methods such as questionnaires or observations.

4.2 Design Methods

This part of the methodology will cover methods related to ideation, prototyping and structuring gathered data in order to find patterns and themes.

4.2.1 Brainstorming

Using Brainstorming as a method is not restricted to a specific moment but is more often used in the early to middle stages of a process, as it is a method used to find solutions to problems (Wilson, 2013). Brainstorming is useful when wanting to generate ideas, find solutions or explore design spaces, and does not require a lot of resources to exercise (Wilson, 2013). In order to succeed with a brainstorming sessions there are some aspects which are important to work with (Kelley, 2001), parts of those are: I) A good description of the problem, as it can help people come back to the main focus of the session if it drifts to far away. II) Make sure to have a warm-up, like a fast-paced word game to get into an outgoing mood. This is more important when people have not worked together before. During these sessions, make sure to get physical or visual, include sketches, mind maps, stick figures and so on, get the idea across. III) Capture and get down the ideas. Do not critique ideas or debate them, that is another aspect to consider, it can be a factor which quickly lowers the energy of the session. IV) Try to make the most out of the energy swifts as well, making use of momentary high curves of energy in discussion as much as possible by building on ideas, taking into account other types of variation or jump back or forward to earlier tracks. Doing this can keep the energy and ideas flowing. V) Numbering each idea can be both motivating and help keep track of where you have been and where you are.

4.2.2 Sketching

Sketching is a method which arose from the need to communicate and explore ideas, using sketches as an aid for the thought (Buxton, 2007). There are several attributes which Buxton (2007) means are of essence for sketching, explaining that a sketch should be quick to make or at least give the impression of having been so. It is used to explore a concept at the beginning of the process but should still be cheap and easy to provide when needed. The form and style that a sketch has should convey that it is a sketch and they usually come in quantity, it is not meant for a sketch to come as a single piece but rather as a collection of meaningful pieces. They should not go beyond the asked question, having more content than what is needed is not positive in the context of sketching, likewise the level of precision should not go beyond the designers certainty of the design. Ambiguity should be an intentional feature to allow different interpretations and to see new relations, inviting to conversations, behaviours and interactions. A sketch should in its state of being complete always be incomplete for a final design (Buxton, 2007).

4.2.3 Prototyping

Prototypes can be seen as one manifestation of a design which allows for exploring sustainability, interaction Preece et al. (2015) and concept among stakeholders, users, design team and the designer (Hanington & Martin, 2012). Realizing a physical representation of the product or interface is an important phase of the process which translates research and ideation into something tangible in a creative way (Hanington & Martin, 2012). The prototypes are usually defined based on the level of fidelity, a prototype can be defined as either low-fidelity or high-fidelity (Hanington & Martin, 2012). Hanington and Martin (2012) also explains that if low and high-fidelity are two end points of this kind of method, it is reasonable that there are points of prototyping variations in-between these two prototyping end points as well.

4.2.3.1 Low-fidelity

Working with low-fidelity prototypes is usually done in the early stages of a design process, more specifically during the ideation phase as these tend to include early concept sketches, sketch models or storyboards (Hanington & Martin, 2012). They are usually easily reproduced, flexible and modifiable, not including all the functionality that the final product is expected to have, at times only having representations of functionalities (Preece et al., 2015). These kinds of prototypes are tools for internal development processes and work as checkpoints for both designers and design team. Using low-fidelity prototypes can open up for constructive feedback and reviews, allowing iterative changes and testing of ideas with stakeholders at an early stage (Hanington & Martin, 2012).

4.2.3.2 High-fidelity

In contrast to low-fidelity prototypes, high-fidelity prototypes are more refined, having basic functions working and frequently having the representing look and feel of the end product (Hanington & Martin, 2012). This type of prototype is useful in later stages of the design process, when conducting evaluations, high-fidelity prototypes can result in feedback relating to aspects of aesthetics, usability, interaction and form(Hanington & Martin, 2012). The form of high-fidelity prototypes can vary depending on what the end product is but are commonly created in software or made into physical models, adding features and details to provide a real user experience (Hanington & Martin, 2012).

4.2.4 Affinity Diagram

Affinity diagramming is a tool used to capture insights, concerns, observations and requirements which are part of research-based collected data, writing them each down on separate sticky notes. This is done to that design implications can be considered. After having written all of them down, they are clustered and arranged by *affinity* into researched-based themes. These themes or categories are not predefined but emerge in the bottom-up process of clustering sub-groups, the overarching themes will become evident when getting higher up in the process of clustering. Affinity diagramming is thus an inductive exercise and the results should be returned to as looking to the voice of the user and as such, also as a partner in design (Hanington & Martin, 2012).

4.3 Applicable Methods

This thesis will use pre-study as a first step in order to establish a knowledge base of the user group. This includes observing and analyzing their behaviour, how they interact with similar installations and what gives them joy. This will be achieved by a fly-on-the-wall observation using secret observer in a design ethnographical way, as it allows for non intrusive observations where the risk of influencing the behaviour of the participant is kept to a minimum. In the same manner, video recording has been excluded from the observations as it poses ethical questions considering the users' inability to give their permission.

Once the knowledge base has been set, the ideation phase will begin with brainstorming, sketching and prototyping. The design process will see heuristic evaluations in the beginning when the prototype is being built, but will be exchanged for usability tests once a robust prototype has been created. A pilot study will be conducted before the first usability test in order to test the interaction and robustness of the prototype and to make sure that the interview questions are easy to understand.

Interviews of caretakers will be used during the usability tests in combination with observations as to provide more insight into the potential thoughts and feelings that the users experience during interaction. The form of interview that will be used is the semi-structured type, using closed questions and a script to ensure that different aspects are analysed and the necessary data is gathered, while still maintaining room for spontaneous questions or thoughts made. Interviews will however not be used during the pre-study, as the focus is to capture the behaviour of the users and what kind of installations they are interested in rather than analyzing their inherent thoughts and experiences. The observations and interviews will be analysed and a suitable analysis method, which has been mentioned, an Affinity diagram of the data.

The choice of not including questionnaires in the design process has been made due to them being less convenient than interviews in the current context; while questionnaires can give more structured and easily analyzed data, interviews can be adapted to the current situation and provides a level of flexibility that questionnaires do not. This can be important in situations where the unpredictability in a diverse group can require tailored questions in order to get the most out of it.

4.4 Technologies

As the installation involves experiencing with the sound, visual and tactile senses, it has to be able to process input of at least one kind and output a minimum of three different channels. Taking these aspects into consideration, the decision to use a Raspberry Pi 3 (see figure 4.1) was taken, which in comparison to the single board micro controller Arduino Uno has a greater capacity to synthesise sound in real time. A Raspberry Pi has both more RAM and a faster processing rate than an Arduino Uno. The input will be mediated with help of sensors, while the audio and visual outputs will be mediated through speakers and LED lights.

When it comes to the software, the music composition software Pure Data will be used as it is an open-source software which allows alteration and synthesising of different kinds of audio files. It is compatible with sensory input and is and as it has an entry-level learning threshold, it is regarded as a tool compatible with the goal of the thesis. The programming of the installation will be in done with the program language Python as it is a commonly used language when working with a Raspberry Pi. The operating system which will be installed in the Raspberry Pi will be the Raspbian Buster system, a system created specifically for working with Raspberry Pi's.

Figure 4.1: An image of the Raspberry Pi model 3B that will be used for the information processing in the installation.

5
Planning

This section will go through the different steps in the design process and give an overview of when things are planned to be executed. The gantt chart below (figure 5.1) gives a good overview of the whole process.

5.1 Time Planning

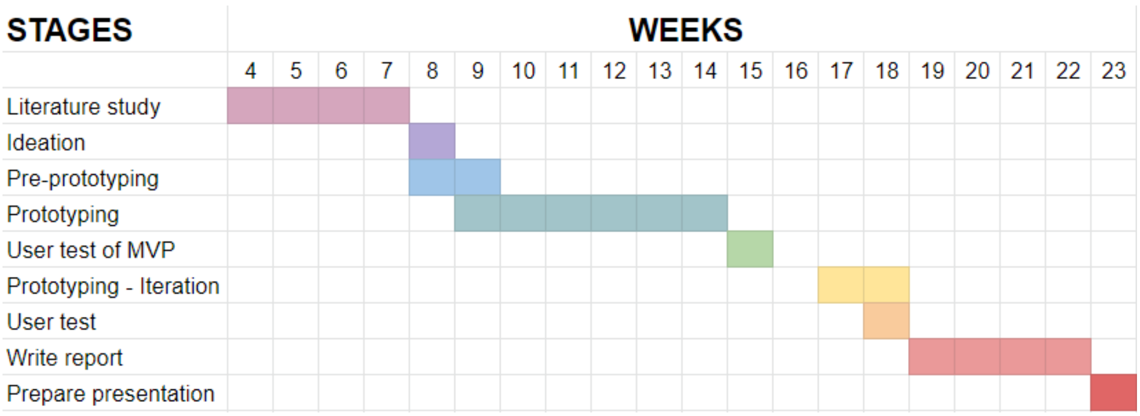


Figure 5.1: A Gantt chart representing the different weeks and planned stages throughout the design process.

5.1.1 Literature Study

The thesis will begin with a literature study, where the theoretical foundation of the project will be established.

5.1.2 Ideation

After getting a better literature ground, ideation will start. This will overlap with the pre-prototyping as the possible components will be found, ordered and tested, which could affect the ideation if a change is needed.

5.1.3 Pre-prototyping

The pre-prototyping phase will consist of more practical information gathering that was not covered in the literature study. It will include looking at videos and other online resources of how to solder, program Arduinos, as well as going through what components we need to order for the prototype etc.

5.1.4 Prototyping

After we know what we want to do and how we want to do it, we will start doing it. The prototyping phase will include portions of ideation and buying components as well, but the focus will be on creating a minimum viable product (MVP) that is ready to evaluate on our user group.

5.1.5 User Test of MVP

This part will consist of choosing and creating the evaluation tools to use during the test, gather data and summarize it.

5.1.6 Prototyping - Iteration

After testing and evaluating our MVP, we will resolve any changes that may be needed for the prototype as well as finalize it for the second user test. The goal at this stage is to have an installation that can be used independently by Eldorado in their daily activities.

5.1.7 User Test

The next tests purpose will be to try out the improved version of the prototype, gather data and summarize it. This is not given an entire week as the previous test as the data gathering tools will already have been made.

5.1.8 Write Report

Summarize the findings, finish writing the parts of the report which are left.

5.1.9 Prepare Presentation

The last week will be dedicated to preparing both the presentation of our thesis and the thesis of which we will be opponents to.

6
Execution and Process

This chapter will describe the different phases and processes of the project as well as the methods behind them. The different stages will be presented in a chronological order if not stated otherwise.

In the spring of 2020, the global coronavirus pandemic had resulted in many public spaces having to shutdown or limit their access to the public in one way or another. In the case of Eldorado, they suspended all of their daily activities and closed the doors to the public. This meant that the usual stream of individuals with PIMD no longer visited the premises which, for the purpose of the project, resulted in the intended target group no longer being accessible. The outcome of this was that some of the initial planned methods had to be revised and changed in order to fall in line with these new restrictions.

6.1 Pre-study

The first step of the project was to establish the requirements, which consisted of an informal interview with one of the staff members at Eldorado. The interview included a guided tour, where the different multisensory environments were presented with all of the accompanying installations. Taking a User Centred Design approach in this phase by trying to understand and focus more on the user gave rise to several questions regarding the target group and their preferences. Some of the questions regarded the target group were i.e: *How do the users tend to interact with the installations? Which installations are the most preferred by the users How have visual, tactile and auditory senses been used in order to create a stimulating experience for the users? What factors are important to keep in mind of the target group and their differences* Other questions asked during this tour included the existing installations: *What kind of installations are being used? How do these installations look, feel and sound like? How often are the different installations being interacted with?*

The outcomes from the tour included the importance of making the installations tangible for interaction and that they are able to support different forms of positioning (i.e. standing, laying down, sitting in a wheelchair, etc.) and motor functions. Two other important factors were the mapping between input and output and having many vibrant colors: Having a clear mapping can be vital for the target groups' understanding of the interaction, while vibrant colors can help to spur curiosity and to keep the user interested and engaged with the installation. Together, all of these questions helped in creating a better understanding for what factors should be considered when designing installations for individuals with PIMD in order to create a positive user experience.

The tour did not only result in different questions being answered, but other, more strict, requirements were also established at this point. Two of these came from the stakeholder, with the first one being that the installation had to be located in the music room and thus be a musical instrument of some sort, while the second one confined the position of the installation to a wall. These two requirements dictated to a high degree the type of ideas developed later down in the process.

To further establish the theoretical framework with all of its different requirements, a literature study was conducted on the subject. The literature study included articles related to general information of developmental and intellectual disabilities, the historical treatment of ID, as well as how multisensory environments and music therapy can be used in order to treat these individuals. Different related works have also been reviewed in order to find inspiration and to guide the design process. Moreover, the literature study also included research of underlying theories of mapping, tangible interaction, design theory and user centered design in order to lay a theoretical foundation for the design process. The outcome of the literature study can be read in its entirety in chapter 2 and 3.

6.1.1 Design Ethnography and Observation

During the exploration of the environments in Eldorado, a smaller design ethnographic study was made where the target group was joined in one of the habitual activities of the day. This activity consisted of a music session where the target group engaged with various musical instruments. The purpose of the ethnographic study was to get a better understanding of the users, the interplay between different individuals, and how they interacted with their surroundings.

A fly-on-the-wall observation was also conducted, this was done in the environment of the department which focuses on stimulation with help of music. The observation was in order to gather data about what kind of instruments the target group preferred, how long and how they interacted with the different instruments, as well as what kind of instruments drew their attention the most. This observation took place during the rush hours of the departments open activities which gave the opportunity to observe a mixed range of individuals within the target group.

Notes were taken throughout both the ethnographic study and the observation and were later analysed.

6.2 Ideation

At the end of the pre-study, the exploration of Eldorado's different multisensory environments and installations continued. This exploration phase served as the starting point for the ideation, allowing for live brainstorming while walking and interacting with the different installations and areas. The ground for the ideas were thus the different experiences and stimulus of the multisensory environments as well as the previously gained understanding of the target group and how they interacted with their environment. As such, the brainstorming method was used in a customized way in order to fit the situation of walking and exploring, giving rise to ideas on-the-go in the different environments. Even though the brainstorming was customized, the aspect of the problem and prerequisites of the project were always included. During this ideation phase, the universal design aspect of designing in such way to make it accessible for as many users as possible, taking the one-size-fits-all approach, was kept in mind when discussing ideas.

6.2.1 Analysis

The analysis of this stage was done by going through the notes and observations captured during the visit at Eldorado, discussing the implications the of different factors that were related to the documentation, factors such as motor function, reactions and similarities as well as differences in individuals. Going through factor by factor and writing down plausible insights drawn from the discussion. Some of the important findings that were made during this stage took their shape as new requirements. These include:

Sound and light - Having a lot of colors in addition to the sound would make the installation stand out in comparison to Eldorado's other instruments and would help to capture the interest of the user.

Adaptation - Due to the varying levels of disability in the users, it was important that the installation supported a diverse group of users. This could include anything from having different sounds or light patterns to being able to change the volume or intensity of the lights.

Gross movement - Due to some users lacking fine motor abilities, it was important that the installation allowed for gross movement.

Direct feedback - As covered in the theory section of Mapping, people with ID can have a harder time understanding abstract relations between entities, meaning that it becomes important to design an instrument where the mapping between the user's action and the instruments output is clear and comprehensible.

Robustness - As for most public installations that supports interaction on a daily basis, some level of robustness is required in order for the installation to not break down too quickly.

Movable components - As it is not uncommon for people with ID to have motor impairments, it was important that the installation also supported interaction from multiple positions, including standing, sitting and laying down.

These points were considered as important to keep in mind when developing ideas for the installation.

6.2.2 Sketching

After the brainstorming and observations were done, the phase of sketching started. Having explored different ideas and possibilities during the brainstorm created a foundation for which the sketching could build upon. Not only did the ideas of the brainstorm become visual but they where also expanded on and improved, giving rise to new thoughts and ideas. The addition of the new requirements also meant that the earlier ideas had to be revisited and changed. Apart from only visualizing the ideas from the brainstorming session, time was also given to come up with and sketch on ideas which had not been investigated before. All of these sketches would then became the foundation for the idea behind the multisensory installation, which was later given the name Multizen.

6.2.3 Multizen

The idea which was chosen to go forward with included three of the human senses: touch, vision and hearing. It revolved around the thought of having a soft, intractable device, that would stimulate the tactile sense when touched, pressed or squeezed, and which purpose would be to activate functions that aim to stimulate the auditory and visual senses, i.e. sound and light. As such, the user would be able to control the sound and light by interacting with this tangible input device, meaning that different sorts of interaction would result in different sounds and light patterns.

Another part of the idea was the thought of having more than one input device, as to allow for co-interaction between one or multiple users and to have a larger amount of variation within the installation. It was also decided that the input devices would be movable up to a range of about one meter as to allow for distanced interaction, which would be necessary if you were to interact with Multizen from a laying or sitting position. As the placement of Multizen was restricted to a wall, the idea took the shape of having the lights attached to the wall like a screen, with the soft input devices attached beneath it.

6.3 Pre-prototyping

Having settled on an idea plausible to realize within the given time frame, the phase of pre-prototyping started. At this stage of the process the importance laid on getting familiar with all of the different technologies available. This was done in order to get an idea of the possible ways to assemble the first prototype, including everything from how it would look to its functionalities, but with an emphasis on the latter. This meant finding sensors, processors and other electrical components that could be used and then combined in a meaningful way.

Three different sorts of input sensors were considered for the input devices: RFID tags, piezo-resistors and flex sensors. The RFID tags were disregarded early due to their low level of embodied interaction. Both the piezo-resistors and the flex sensors allowed for a more tangible input device where touching, pressing and squeezing were possible. In the end, the flex sensors were selected as the input sensor due to their attribute of being bendable, as well as the fact that they gave more accurate data measurements when compared to the piezo-resistors.

Due to Raspberry Pi being better at synthesising sound in real time compared to the Arduino Uno, the Pi was chosen as the go-to processor. Unlike the Arduino however, Raspberry Pi can not receive analog signals as input, which would be necessary if one wanted to make an instrument that reacts to small, gradual, changes in pressure. Instead, an analog-to-digital converter (ADC) was used to convert the signals from the flex sensors into analog values that the Raspberry could read. However, the input values fluctuated to the extent that a decision was made to use the Arduino for input processing instead. As the Pi's capabilities of synthesizing sound still preceded the Arduino's, it was kept as the main processor for the sound synthesis.

6.4 First Prototype

Once the different components had been individually tested and evaluated, the next phase of the project consisted of connecting all of these different things together in order to create a more cohesive experience. As seen on figure 6.1, the first prototype consisted of a cushion, an Arduino, a Raspberry Pi and LED lights. The cushion, which can be seen without its covering cloth on figure 6.2, consisted of three flexible sensors attached to a foam. Due to the resistance across the sensors increasing as they bend, it was possible to register not only when they were bent but also how hard they were bent. This data was registered by the Arduino and passed on to the Pi for further processing. The Raspberry Pi can be seen as the brain behind the setup; using Python at its core, the Raspberry included all of the logic for processing the input and executing the output. The touch input from the cushion was mapped to a 'strength' variable which was then used to control a 5x4 grid of LED lights.

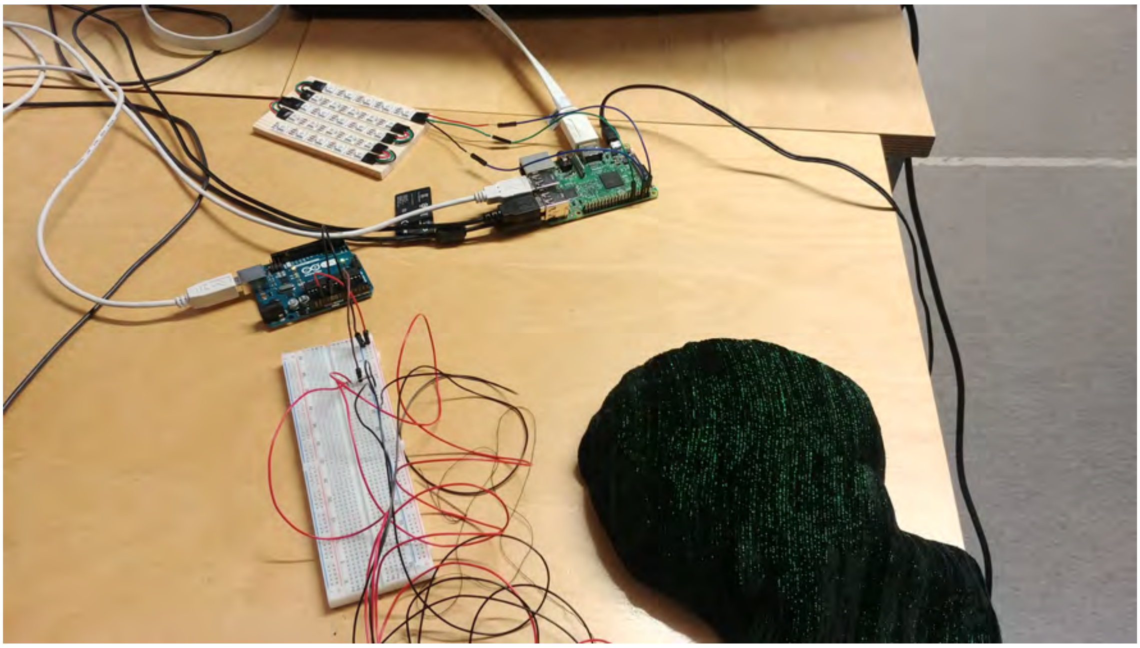


Figure 6.1: The first interactable prototype. Three touch sensors inside of the green cushion is connected to an Arduino, which registers the touch input and sends it forward to a Raspberry Pi. The Pi handles all of the logic, which includes controlling the lights and sound.

Figure 6.2: The inside of the first prototype for the cushion can be viewed to the left, while the covering cloth is seen laying on the right.

6.4.1 Lights

The activation of the lights were connected to the input device, i.e. the cushion, and would accordingly light up depending on the input data received. By applying a pressure of intensity x, the strength value would surpass a specified threshold and result in the first row of LEDs lighting up in a blue color; increase the pressure by twice as much and a second row of LEDs would light up, bringing the total amount of lit rows to two. If the person were to loosen the pressure and thus bring down the strength value, the second row of LEDs would turn off, leaving only the first row of LEDs on. As such, depending on how much pressure were put on the cushion at any given time, the number of lit lights would change in accordance.

6.4.2 Cushion

As the cushion acted as the interface between the user and the instrument, it was important that this device felt good to interact with. stimulated the tactile senses in a satisfying way, while also having a pleasant and interesting visual look. As seen in figure 6.1 above, the chosen fabric of the cushion was striped, with one material consisting of a green shimmering fabric, while the other consisted of a dark, soft and more rough texture. Two more fabrics (see figure 6.3) were chosen as a preparation for the addition of more cushions to the instrument. Together, these three fabrics were chosen based on their visual and tactile attributes: level of attention, friction, colours, shimmer and the novelty of the texture.

Figure 6.3: The three different types of fabrics that were selected for the project, based on visual and tactile attributes.

6.4.3 Sound

Sound was at this stage not yet included as the aspect of which form the sound would take was still under discussion. Different alternatives were considered, including weather it would be a pre-recorded sound, a music snippet or an instrumental note. It was also discussed whether the sound would start when the user first presses on the cushion and stop after the it had finished playing, or if it would be a more dynamic process where the sound would play for as long the user pressed the cushion and only come to a stop when they release the pressure from it.

6.4.4 Heuristic Evaluation

After having assembled the first prototype with the lights working in correspondence with the sensors and with the cushion having a plausible look and feel, the first heuristic evaluation was made. The heuristic evaluation was done by the designers in such way that turns were taken to interact with the prototype and during or after the interaction, comments of the experience were given. Afterwards, those comments were discussed and analysed in the perspective and understanding of the user group and stakeholders. Taking help of the knowledge gained from the pre-study regarding the different disabilities of the target group and the the knowledge gained from having visited Eldorado, while keeping the prerequisites of the stakeholders in mind. Looking at the different parts of the prototype, including tactile, visual and auditory aspects, the prototype was evaluated in respect to the mapping, the level of visual attraction and the universal designs accessibility aspects of *Simple and Intuitive use*, *Low Physical Effort*, *Size and Space for Approach and Use.* These aspects were thought to be the most consistent with the needs of the target groups. Interacting with the prototype with these aspects in mind allowed for a more plausible evaluation and understanding of the possible interaction of the user group.

6.4.5 Analysis

Discussing the experience of the interaction with the perspective of the user, multiple issues were found, all of which regarded the flex sensors. The first conclusion was that the cushion was not sensitive enough, which forced the user to apply more strength than desired when pressing on it. This was seen as an issue as the user group, both based on litterateur and the explanation of the stakeholder, can have difficulties with motor functions. Minimizing the need of demanding actions or movements by increasing the sensitivity of the sensors was an important factor to consider in regards to making the design more inclusive, and a criteria that the current flex sensors did not fulfill.

The flex sensors also had the problem of plasticity; if the user applied a high pressure to the sensors and thereby bending them by a large degree, the flex sensors would take a couple of seconds before they were straighten out to their original state. This meant that the Raspberry Pi would receive a continuous stream of data causing the lights to activate even though the user stopped touching the cushion. This made for a poor interaction considering the importance of having a clear and comprehensible mapping between the input and the output.

Another insight was the fact that the sensors did not cover the entire pressing area properly; even though the cushion was in size with the flexible sensors, the edges of the sensors were unable to register presses by the user. This made the *actual* area of interaction much smaller than implied by the cushion, which could result in confusion and misinterpretation. Thus the need for altering the size of the cushion came into discussion.

6.5 Second Prototype - First Iteration

Through the entire process, heuristic evaluations were made to test and evaluate the output, feel and plausibility of the prototype. With help of this method, aspects in need of improvements were found and worked on. In order to reach a minimum viable product which could be tested on users, a few things had to be revised.

6.5.1 Lights

A change that was made related to the hardware was the addition of an up-scaled LED grid. The 5x4 grid was replaced with an 8x4 grid attached to a thin wood board, as such increasing the total amount of lights from 25 to 32. A frosted acrylic glass was placed in front of the LEDs in order to spread the light more evenly across the surface and to give the effect of each LED being bigger than it actually was. The acrylic glass also served a secondary purpose of protecting and hiding the LEDs. The glass was in turn held in place by a thicker wooden frame (see figure 6.4 below). The underlying thought of this design was to create a prototype which could be good enough to use in a user test, giving it a look and feel more in line with the concept.

Figure 6.4: The setup of Multizen during the usability test. The LED grid can be seen lightning up in blue as pressure is being applied to the cushion.

6.5.2 Cushion

During the first iteration, the size of the cushion together with its cover underwent multiple changes. During the heuristic evaluation, it became evident that the size of the cushion needed to be smaller in order for the flex sensors to be able to reach all the way out to the edges. The first change that was made to the cushion was to reduce its size by around one c in diameter. Although this made the cushion more responsive towards the edges, it did not solve the problems of sensitivity and plasticity. As these problems had more to do with inherit properties of the sensors themselves, rather than the result of a poor design, they were addressed by changing the sensors altogether.

Due to the importance of having a clear mapping between cause and effect for the targeted interaction, it was important to have a sensor which could sense small changes in pressure without the need of applying extensive force to it. One type of sensor that was tested and which fulfilled these criteria was a multi-sensor module (see figure 6.5). The multi-sensor was hooked up to the Arduino, where the atmospheric pressure of the sensor was registered, while the sensor itself was inserted into a balloon. Using the multi-sensor's pressure measurement to sense changes in pressure proved to be a successful change, as not only was it more accurate in its readings but it did not suffer from any sort of plasticity either. In order to make this change possible, the inner part of the cushion was changed into an air concealed plastic bag (see figure 6.6). The plastic bag was the result of multiple attempts of creating an air-proof, soft container, where the air would be kept from leaking out over time, which would have been the case for a balloon. The change of sensor proved to be useful as the sensitivity and data accuracy of the cushion improved, allowing the user to interact with it with more ease.

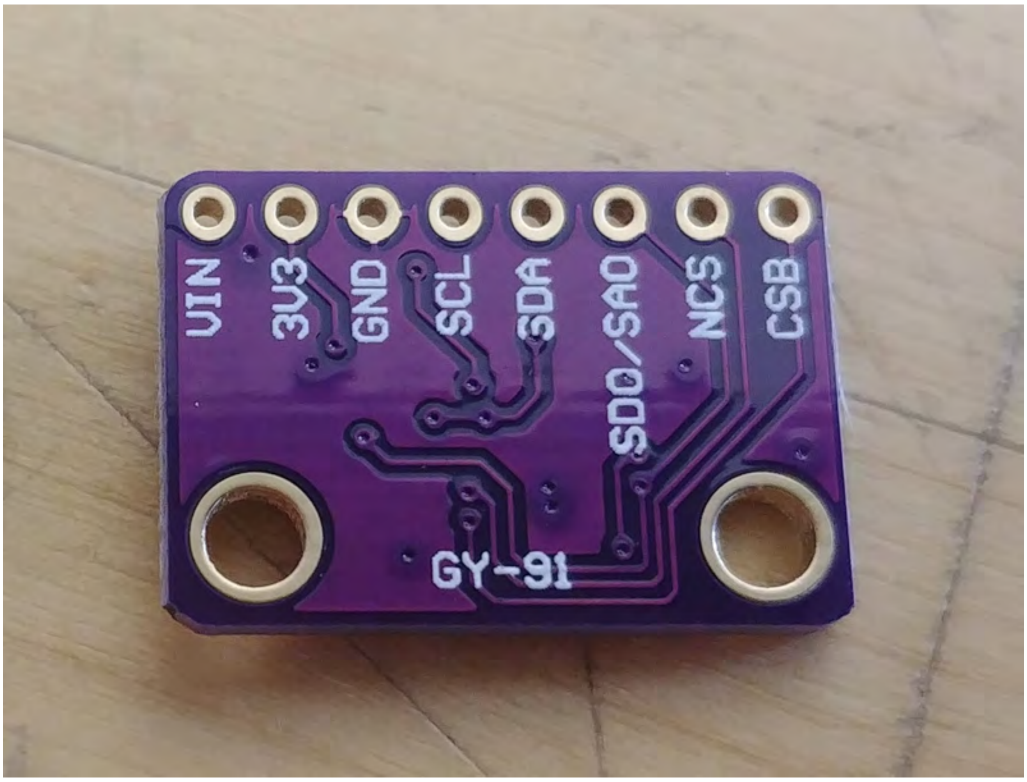


Figure 6.5: The multi-sensor module that was used inside of each cushion in order to register pressure applied to the cushion.

Figure 6.6: An air-proof container that was made by melting a plastic bag and gluing it to the neck of a bottle.

6.5.3 Sound

At this stage of the project, sound was added to the prototype in a similar way as the lights; the input data from the cushion was sent to Pure Data, where it was converted into a value of frequencies, ranging from 0 Hz to 1000 Hz (the Pd patch in its entirety can be seen in Appendix A). The strength value was mapped in the sense that no pressure gave a frequency of 0 Hz while a harder squeeze resulted in 1000 Hz, with squeezes in between resulting in frequencies between those two values. The frequency was then used as input to a sinus wave, which outputted sound to a connected Bluetooth speaker. A Bluetooth speaker was used due to Raspberry Pi 3's limitation to having multiple devices running on Pusle Width Modulation (PWM). Having both lights and analogue audio controlled by PWM can result in interference (Cox, 2014), as such a Bluetooth speaker was used to output the sound.

In addition to altering the frequency when pressing the cushion, a variable for controlling the volume was also implemented. This variable was mapped to the velocity of which the cushion was pressed, with a fast press resulting in a higher volume. Not pressing the cushion would thus result in no sound being outputted.

6.5.4 Pilot Study

Once the prototype incorporated all of the essential parts of the concept, i.e. a way for the user to control the lights and sound in reliable manner, it was time to do the first user test. Due to unforeseen circumstances, by the time the pilot test was ready in late March, the pandemic Covid-19 had affected most public places in Sweden and Eldorado was no exception. Eldorado had to shut down most of their operations, including their daily drop in. This meant that the target group of individuals with profound intellectual and multiple disabilities were no longer visiting the premises. As such, instead of testing the prototype with the target group and interviewing their respective caretaker, a member of the staff at Eldorado participated in the pilot study instead. This was done in order to get feedback from an expert of the domain who has worked with the target group for years, rather than only conducting heuristic evaluations within the two-person team of designers.

The study started with having a shorter introduction of the purpose of the test. In order to understand the users experience in a more direct manner, the participant was informed on the method of Think Aloud and how to execute it while interacting with the prototype. Further more, the participant was made aware that notes would be taken throughout the interaction as well as during the interview towards the end of the session. The participant was also informed about their full anonymity during the test. When there was no more information to give, the participant was asked to start interacting with the prototype when they felt ready. During the Think Aloud, notes and comments were written down in a document, while the interview questions were recorded in an interview form.

6.5.5 User Test

Due to the pandemic, it became difficult to schedule appointments with participants as the department encouraged the staff to stay home and keep distance from other individuals. Thus the main study was conducted two and a half weeks later and consisted of an usability test, including four members of the staff at Eldorado.

The test was conducted in a similar fashion to that of the pilot study: the participant would enter the room and sit down at a table. The LED grid together with the cushion were placed on top of the table with the Raspberry and Arduino hidden behind the grid (see figure 6.4 for reference). A brief introduction was held for the participant, introducing them to the purpose of the test as well as informing them of their full anonymity. The participant were told to interact with the prototype and were then allowed to interact with it for as long as they wished, while any spontaneous comments were written down. Once the participant fell silence, the interviewer began to ask questions related to the experience of interacting with the prototype and what they thought the experience of the intended target group would be like.

One difference between the pilot study and the expert review was that Think-Aloud was removed as a method of accessing the participant's thoughts and feelings. The reason for this had to do with redundancy; the participant in the pilot study answered most of the questions in the interview during the Think-Aloud, which defeated the purpose of having an interview after the interaction was done. In order to keep the gathered data consistent across all participants, the Think Aloud, rather than the interview, was removed from the test.

6.5.5.1 Semi-structured Interview

The interview consisted of seven open-ended questions which revolved around the participant's thoughts and feelings of the prototype, as well as their thought on how the target group could experience it (the interview questions in their entirety can be seen in Appendix B). Due to the participants being Swedish speaking, all of the questions were formulated and recorded in Swedish. For the convenience of this report, the questions and results mentioned below have been translated into English.

All of the questions were asked in the same order for all the participants and their answers were written down in a questionnaire form created in Google Forms. Four out of seven questions were formulated in the way of "...do you believe that...", in order to make clear that the answers were based on speculations grounded on the knowledge and experience of the experts. One question regarded their experience of Multizen while the remaining two question allowed the participants to freely speak about their thoughts of the installation and if there was anything they believed could enhance the prototype for the target group. The interview questions were phrased in such way that they would reflect the staff's experience of interacting with the prototype and how well they think it would suite the intended target group and their needs.

6.5.6 Analysis

After the tests were done, the feedback was reviewed in order to analyze and extract the factors which would help to improve Multizen and the experience that comes from interacting with it. Unlike what was previously mentioned in the methodology chapter, the analysis of the data was not made with help of an Affinity diagram. Considering the low numbers of participants and data, the analysis was done in such way that the data was read through, taking out and using reoccurring comments or topics as a base for discussions. All of the comments were taken into consideration, with the ones involving constructive feedback being further analyzed and discussed.

The overall answers and feedback received from the evaluation were positive, where the employees commented that they believed that the mapping between input and output was fitting. Also mentioning that they believed that the target group would have appreciated the interaction as it was not too complex. Other comments also lifted that they believed the prototype of the input device would appeal to the users, both by tactile and visual stimulation.

The factors which were primarily addressed with constructive feedback regarded the sound and the lights. Three out of five participants suggested to make use of a sound which could be "lower", "softer", "morphing", "more exciting", "varying" or just "a more fun sound". One argument that was given had to do with the occasional tendency of the target group to interact with one installation for an extended period of time, making it important to have a sound which could be played in long intervals without annoying or irritating the user or other individuals close by. Thus, a more pleasant sound would make a good improvement for the experience of Multizen within the target group.

Constructive feedback regarding the lights was given by four out of five participants, with one participants saying that adding some other colour to it, rather than just having one colour all the time, could be a stimulating addition for the user group. One other participant mentioning that creating some kind of animation or change with each new press could contribute to increasing the interest within the target group. Two participants also suggesting the addition of having several colours displayed at the same time as a good feature to have.

Furthermore, visual aspects of Multizen's decoration and look were also addressed, with one participant saying that decorating the installation with more eye-catching colours or shimmers could heighten the chance of grabbing the users' attention. Another participant mentioning the need of not letting electronics show, emphasizing the need of having such parts out of sight.

One comment which touched upon the interaction itself, was the one meaning that an interaction of having to press with speed in order to increase the volume could turn out to be a challenge for the target group. Considering that pressing down on something quickly with the hand can require more effort depending on the individuals capabilities of motor function.

The discussed themes derived from these comments ended up being the following:

A change in sound - making it more pleasant or fun.

Addition to the lights - adding colour or some kind of animation, something changing form time to time.

Making it beautiful - not having electronics show and making the hardware of it more beautiful in some way.

A change in volume control - change the way the volume is increased in order to minimize the effort in motor function.

6.5.7 Idea evolution

Already after the pilot study, the first ideas of how to improve Multizen started to evolve. As comments about the visuals of the light were given, ideas of having different kinds of light shapes started to arise. Discussions leading to the idea of creating different symmetrical shapes, with each shape being connected to one of the input devices. At this point, another idea arose: in order to keep the mapping as consistent and clear as possible, why not change the physical shape of the cushion to reflect the pattern it creates on the LED grid? To give an example, the square-shaped cushion used during the test would keep the behaviour of turning on the LEDs in a square-shaped pattern, while the other two input devices could consist of a circle-shaped cushion connected to a circular pattern and a triangular-shaped cushion connected to a triangular pattern. Considering that more than one input device was part of the original idea, having a connection between the shape of the cushion and the light it is mapped to thus became a combination of a new idea with an already existing one.

Additional ideas started to form after the user test, where more aspects which could be improved upon were brought to light. These included: the way volume was mapped to the input devices, the addition of more colours and different combinations, as well as making Multizen more attention grabbing by altering its physical parts. All of these factors were further discussed before starting the second iteration of the prototype.

7
Results

In this chapter, the final result of the project will be presented, where the first part will cover the different features and the visual representation of Multizen while the second part focuses on the design factors behind these implementations.

7.1 Multizen result

After having conducted the usability test with experts within the domain, the last iteration of the project started. The aim of this phase was to make the interaction more interesting and engaging, while also increasing the robustness of the prototype. Different changes were made to almost all aspects of the prototype. One of the more obvious changes made was related to the size of the LED grid. The Arduino and Raspberry was also attached to the backside of the LED grid in order to hide them from view, while the cables connecting the cushions with the Arduino were wrapped into soft cotton and covered in order to protect them while also giving them a soft feeling if they were to be touched or grabbed. Likewise, the sides of the grid were covered with a gold/yellow shimmering textile in order to cover the sight of the hardware and also make it more colorful and fun to look at. Multizen in its entirety can be seen on figure 7.1. Other changes regarding the light, sound and cushions are described more in detail in respective section below.

Figure 7.1: An image of the final prototype, showing the LED grid lying on a table with two of the cushions beneath.

Multizen now works as such that when you press on a cushion, the light will activate in accordance to the pressure, with each row of lights turning on depending on the amount of strength used. Each cushion having its own shape, both when it comes to its physical appearence and the pattern displayed on the LED grid. The cushions also allows for simultaneous pressing, where overlapping lights is colored differently. The sound follows the input in the same way as the light do, increasing then pitch and volume depending on the strength and velocity of the pressure. If there is no interaction within one minute the grid will enter idle mode and start displaying a light animation on the grid.

7.1.1 Lights

One of the changes done from the previous prototype were the addition of more lights, making Multizen bigger in order to cover a larger area of Eldorado's wall. This was done by expanding the size of the grid, changing the number of lights from 4x8 to 12x8, increasing the total number of lights from 32 to 96. The size of each square in the grid was also increased from 4x4 cm to 6x6 cm. With this came also the change of acrylic glass used for the front, with an altered design of attaching it directly to the wooden frame instead of the frame holding the glass in place. The overall measurements for the LED grid thus became 80x120x4 cm.

Beyond the addition of more lights and a bigger grid to the prototype, the behaviour of the lights also changed. These changes consisted of two parts; the first change of the behaviour consisted of adding more colours to each pattern as well as changing how they are displayed. Instead of having one colour filling the whole grid, they are now presented as gradients: going from one color in the bottom to another one in the top. The colours of the gradients are randomized from a selected pool of colours each time the user presses the cushion. The second change is related to the shape of the lights, where it now represents the shape of the cushion that is being pressed. As an example, pressing the square will get the lights lit up in a square shape, in the same way as in the first prototype (see figure 7.3 for reference). Pressing on the circular cushion will instead lit a circular pattern, which can be seen in figure 7.2.

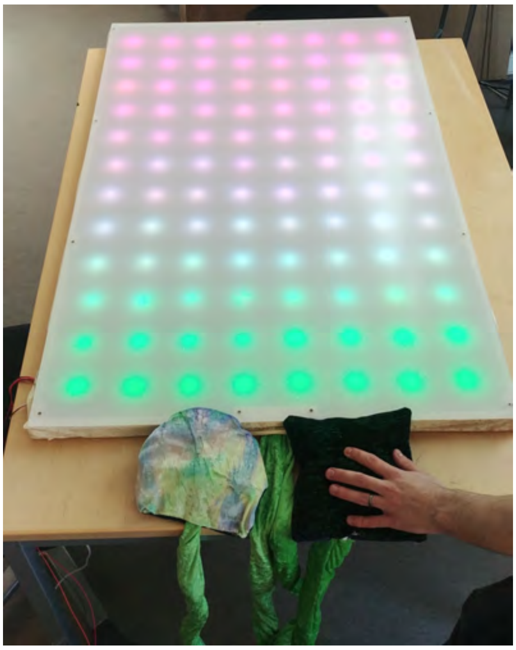


Figure 7.2: Applying enough pressure to the squared cushion will make the LED grid light up from the bottom to the top, gradually shifting from one color to another.

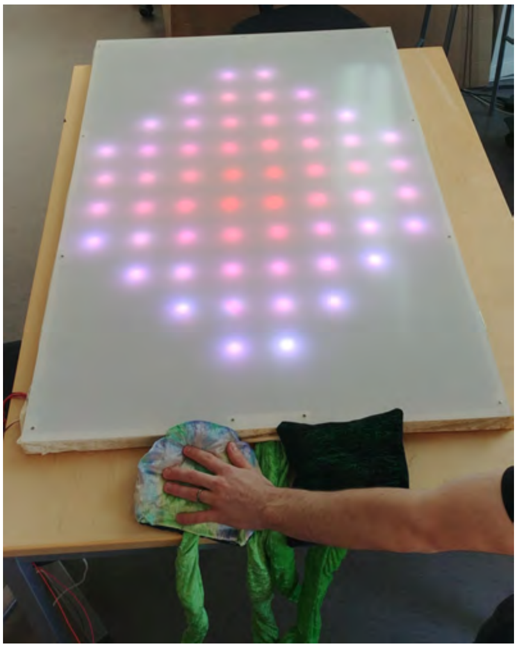


Figure 7.3: The circle-shaped cushion is being pressed to its maximum, with the pattern lighting up from the middle and extending outwards.

Multizen was also made to support simultaneous interaction, where pressing both cushions at the same time would result in a new colour forming where the patterns overlap on the grid, according to the blend mode 'Color Dodge' (see figure 7.4). If the pressure of one of the cushions diminishes and the pattern of that cushion becomes smaller as a result, the parts that do no longer overlap will return to the original colour that was set before the overlapping took place. This also means that if the circle is pressed while the square is being pressed on to its fullest capacity (i.e. all LEDs are lit), the circle will lit up in the overlapping colour, thus not showing its original colour until the square stops overlapping with it. The overlapping colour is fixed rather than random, as having it random sometimes results in the overlapping color being the same as the color of the pattern it is overlapping with, which would make it hard if not impossible to distinguish.

An idle mode was also implemented in order to make Multizen more attractive, as an attempt to catch the users attention and spur curiosity. Making it stick out more in its environment than what it else would if the LED-grid was entirely turned off while no interaction (see figure 7.5). The idle mode consists of white-colored LEDs that slowly moves from the top towards the bottom, similar to rain droplets falling on a window. Multizen will go into idle mode after one minute of inactivity and cancels as soon as a cushion is pressed.

Figure 7.4: If both cushions are pressed, the overlapping lights will receive a new distinctive color according to Porter and Duff's 'Color Dodge' (Pedersen, 2013)

Figure 7.5: During inactivity, Multizen will enter idle mode where white-colored LEDs will move slowly from the top of the grid down to the bottom.

7.1.2 Cushion

As Multizen got bigger, one additional input device with a unique light pattern, sound and look and feel was added. As seen on figure 7.6, the second cushion took the shape of a circle, with a softer tactile feel and more colorful look to it, as an addition to the square-shaped cushion. During the earlier ideation phases in the project, and as hinted in section 6.4.2, Multizen was imagined as having three unique cushions to interact with. However, due to hardware-related restrictions in the multi-sensors used for the project (i.e only supporting two I2C addresses), the final prototype only supported two unique cushions.

In addition to changing the number of input devices used, the cover of the cushions also underwent some changes. First off, a new square-shaped cushion was created as a result of the evolved concept, where more more emphasis was but on making it square-shaped and better reflecting its pattern. As there were no limitation to how big the air-proof plastic bag could be, compared to the earlier flex sensors which the old case was designed after, the size of the cushion also increased to be more aligned with the size of the very first prototype. Secondly, the covers for the cushions were designed to be removable, allowing the separation between the plastic bag and the cover (see figure 7.7). This was done in order to facilitate the maintenance of the covers: making it easier to wash and keep hygienic while also allowing for worn out covers to be changed. A hook-and-loop fastener was used for this improved version of the cover in order to open up the cover and remove it (see figure 7.8). The plastic that was used for the air-proofed bags were also double-folded at this stage in an attempt to increase the durability of them.

Figure 7.6: Both cushions laying besides each other, with the circle-shaped cushion to the left and the square-shaped to the right.

Figure 7.7: The left side of the image shows the internal cover of the square-shaped cushion where the plastic bag and multi-sensor is located. The external cover is laying to the right.

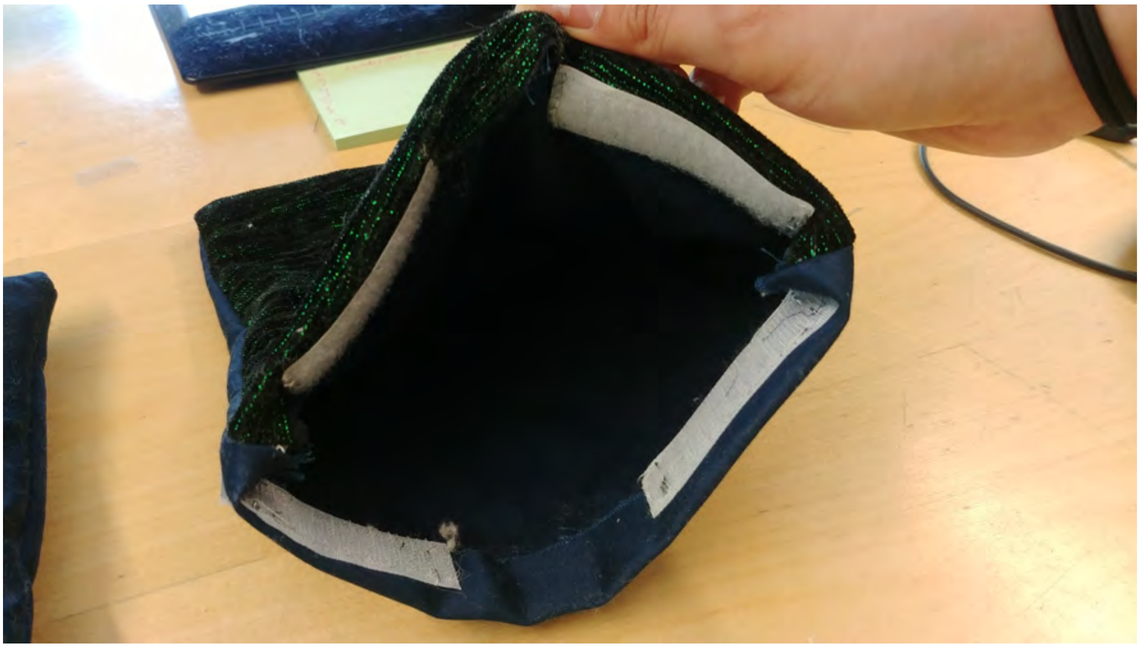


Figure 7.8: A hook-and-loop fastener was used in order to keep the inner cover in place while also making the external cushion easily removable.

7.1.3 Sound

The sound in this final phase is in general the same as in the previous prototype: it still consists of a sinus wave which the user can alter the frequency of. However, in this version, the sinus wave was also changed distinctive 'steps' in order to give it more characteristics similar to that of notes. In addition, the speed of which the Python script and input data was read was increased from 50 times/second to 2000 times/second. Increasing the rate in which data is received affected the sound in such a way that even the smallest of changes in data resulted in an output sound. This made the sound react faster to the user's input as well as make it sound more diverse, especially in cases where the pressure would be constant. Lastly, the pitch of the sinus wave was lowered while the range in frequency between minimum pressure and maximum pressure was shortened in order to prevent the maximum output to result in a high and unpleasant pitch. The circle-shaped cushion was also made to have a darker pitch in relation to the square-shaped as to make the different sounds more distinct. Playing both sounds simultaneously will make one sound appear from the left speaker and the other from the right, assumed that a stereo speaker is used.

7.2 Theoretical result - Factors to consider

Multizen is based on five key factors that were identified throughout the design process. These factors have their roots in the development of the requirements that were established during the pre-study and then refined by the feedback given during the usability test and the interviews with the employees. The factors are the following:

i) Stimulating more than one sense.
ii) Customizing for different capabilities.
iii) Having a clear mapping between input and output.
iv) Balancing the level of complexity in the interaction.
v) Having an installation that both looks and feels appealing to the user.

Stimulating more than one sense denotes, as the name suggests, that more than one sense should be integrated in the design. *Customizing for different capabilities* means that an installation should be designs in such a way that it supports different levels of cognitive and motor impairments. *Having a clear mapping between input and output* deals with the fact that the target group can have difficulties with understanding abstract relations. As such, the mapping between the user's input and the output from the installation has to be clear. *Balancing the level of complexity in the interaction* includes designing an interaction which is not too challenging for the users. Lastly, *Having an installation that both looks and feels appealing to the user* represents the visual aesthetics of the installation and the importance it has on maintaining the user's curiosity and engagement.

The above factors are the recurring points of which Multizen was built on, which means that Multizen can be seen as one possible outcome to how these factors can be applied in order to create a stimulating installation for individuals with PIMD. The five different factors that were identified throughout the process should be considered as guidelines and not strict rules, as the purpose of them is to guide designers in their process rather than instructing them what to do. Although these factors were the ones identified during this thesis as being important for this type of installation, it is plausible to think that other, undiscovered, factors exists. As such, the five identified factors should be considered as an addition to the pool of factors that exists when it comes to creating positive experiences for individuals with PIMD through the use of multisensory installations.

The five factors that were identified in this thesis are of importance as they address the core of what an installation should include in order to be able to create an experience which is stimulating, understandable and usable for individuals with PIMD. As an example, not including the factors of *customizing for different capabilities* and *having a clear mapping between input and output* factors could exclude a part of the target group. Excluding the use of a clear mapping could result in the interaction becoming more abstract and thus risk that parts of the target group (those with a lower mental capacity) will not understand how to interact with the installation. Not understanding the outcome of your action is something that in turn can contribute to an overall negative experience and thus should be avoided. Customizing an installation in order to allow users with different capabilities is to work towards an installation which includes as many individuals in the target group as possible. As Caltenco et al. (2012) also explains in the making of Polly world, having customizable installations can help users to personalize their interaction and experience. Being a contribution to a positive experience. The same principle applies to the factor of *balancing the level of complexity* as this also touches upon the varying understanding of an entity and the interaction that comes with it. This factor is in line with what van Delden et al. (2019) mentions, designing an installation with a complexity that is adequate is important as something highly challenging or not challenging enough can result in a negative user experience. The factor of *stimulating more than one sense* was identified as important as the concept of a multisensory environment implies the stimulation of more than one sense, but also for the reason to create an experience which is dynamic and allows for playfulness and exploration rather than a static experience. A multisensory installation should thus be able to give more stimulation to a user than what other, non-multisensory, installations can. The last factor of *having an installation that both looks and feels appealing to the user* is a part needed in order to get the user to want to interact with the installation. As individuals with PIMD can have a lower mental capability and maturity - capturing the attention is important in order to spur interest and curiosity. Excluding this factor can risk the creation of an appearance which will not attract the user or invite to use. As done in Multizen with the idle mode and colorful cloth; having a light pattern showing even when there is no interaction and the addition of different colours to different parts of Multizen is a way of addressing this factor. These implementations were made with the purpose of making Multizen stand out, grab attention or invite for exploration.

A dissuasion of how these factors were identified and to what extent they contributed to the design will be covered more in depth in chapter 8.

8
Discussion

In this chapter we will discuss different factors which we believed influenced the direction that the design took and consider uncertainty factors of the project. Ethical issues will also be considered and discussed, ending with the future work where we speak of improvements and further developments.

8.1 Process and Result

As mentioned in chapter 6, the project was reassessed as a result of the COVID-19 pandemic. Due to government recommendations of social distancing many public places and organisations had to shut their doors to the public, including Eldorado. This was especially important in their case as the majority of their visitors were in the risk group for COVID-19 according to Sweden's National Board of Health and Welfare (Socialstyrelsen, 2020). Beyond not receiving any visitors, most of the staff at Eldorado also worked from home, which made it more difficult to find a day and time for the evaluation where multiple people were in the building at the same time. This affected the process in a couple ways; first off, due to the issue of availability, both a pilot test and a usability test got planned to being held on the same day. Multiple appointments were made for this first set of tests, with one of these including an individual from our target group. This was possible as Eldorado still received scheduled individual meetings at that time. However, by the time of the test, all activities had been shut down and the individual meeting did not take place as planned. Moreover, all but one of the staff members had either left early or chosen to work from home. This meant that only the pilot test could be held that day and the usability test was delayed by two weeks. During the time in between the pilot test and the usability test, both the concept as well as the prototype were being worked on. Something which could have affected the development of our design as the remaining feedback was not present until later in the process. Leaving time for us to start rethinking the idea based on solely the data of the pilot test rather than the entire data set which was available after the entire evaluation. It is hard to tell how much of an effect the delay had for the process and final prototype but we do believe that more time would have been available for a further evaluation if everything had gone according to schedule.

Secondly, the components that were used for the final prototype, including the multi-sensor module and the acrylic glass, did not ship in time from the supplier due to COVID-19 related delays. This meant that some parts of the prototype, including the look and feel of the LED grid together with the feature of having simultaneous interaction, could not be tested and evaluated until later in the process. To give an example, at the time of building the LED grid it was believed that adding a second multi-sensor would be similar to adding the first one. As such, both the wires connecting the sensor to the Arduino as well as the underlying Python script that was responsible for Multizen's behaviour were all prepared in advance for the arrival of the second sensor. However, as we would later find out, the addition of a second sensor required a different hardware configuration, not to mention a larger restructure of the script, which meant that some previous work had to be redone. This was not an issue per se, as reworking and iterating on previous work is a core part of any design process. The problem was rather that the addition of one of the biggest features of Multizen, i.e. simultaneous interaction, came in late in the process, which meant that all of the accompanying bugs and problems that arose with the implementation of it had to be fixed last minute. This, together with the limitations in availability for the staff members, resulted in the absence of a usability test for the final prototype. Questions regarding how this could have effected the results of the project are discussed more in depth in section 8.1.1 below.

Looking at the result and thinking about the feedback given about the design there were some factors which were recurring. During the pre-study of the target, when exploring the multisensory environments which were open for use, it was noticeable that most of the installations and object that were in the environments had as intention to stimulate more than one sense. Having objects which stimulated the tactile and the visual sense, while other objects could combine the stimulation of the auditory and tactile senses. Most of the things had at least two stimulating aspects which combined colours, lights, sounds and pleasant surfaces or rougher surfaces. This was also a comment given early on in this project, to include as many senses as possible when thinking around the design in order to keep the target group engaged. Seeing how the related work, which was mentioned in earlier chapters, also implemented objects which included as many senses as possible, it is reasonable to believe that designing something which includes the factor of several senses can be of importance for the design in order for it to be positively experienced by the target group. Not to mention that it can contribute to a more varying and interesting installation.

In addition to this factor, it also became noticeable that there was an intention in the different objects and installations of the multisensory environments to grab the users' attention, using stronger colours or shapes to make itself eye-catching. What we learned through the process was precisely the need of having an appearance which would not disappear in the crowd. Getting comments during the evaluation on how to make Multizen more attention grabbing and more fun, helping us understand that it was of importance to make the user want to explore the installation.

Another factor which affected the design of Multizen, and which was present through the entire process, was the need of customizing for different capabilities. The factors mentioned in the Universal Designs *Size and Space for Approach and Use*, speaks about the need to design in such way that different positioning, clear sight and aid from another part are made possible. This factor was also mentioned by the employees at Eldorado and they showed us in which way the already existing installations had been customized to meet these need. Considering that the target group consists of individuals with several differences in motor functions and other bodily capabilities, this factor became important in order to include as many of the target group as possible. Trying to implement this into our design, we decided to make the cushion movable, making the wires longer, supporting different positioning and distance from the installation. The though of making it soft and easier to press on without a lot of strength was also an attempt to meet this need. The range of the cushion was however limited to a distance of about 1.5m in order to not let the input device end up too far away from the LED-grid that the mapping between them would become unclear. Having in mind (Norman, 2013) important aspects of mapping with proximity in space between two entities as well as (Goldbart & Caton, 2010) talking about the need to have a clear cause and effect for the target group. Speaking to the employees in Eldorado also made us understand that having a good mapping will aid the target group in understanding that they are the ones causing the result and having the control. Allowing for exploration and playfulness when interacting with the installation. This was thus something we considered to be important for the design and influenced the choices of not allowing to much distance and mapping the lights animations shape with the shapes of the cushions. Something that contributed to the goal of making the system as responsive as possible to the input in order to let the target group experience a direct feedback of their action. Consisting with the aspect of *Perceived coupling* in the Expressive Representation of the Tangible framework in 3.4, meaning that if an outcome is perceived as a effect of an action, it can enhance the users experience of the system. On the other hand, without a final evaluation it will be difficult to get a better understanding of how these implemented factors would actually be experienced by the users.

The factor of creating something which is not too complex or challenging for the target group, influencing both the type of interaction and physical nature of the input device. As mentioned by (van Delden et al., 2019) in the work with The Interactive Ball, the individuals in the target group can differ in both mental and physical abilities. Addressing the need of not making the interaction too challenging as it can lead to a negative experience and the sense of failure when trying to interact. Something which we also observed in the multisensory environments at Eldorado, the ease in use of the different artifacts. In line with the Universal design aspect of *Simple and Intuitive Use* arguing for, among other things, the importance of making it easy to understand and interact with the design as well as to avoid unnecessary complexity. Trying to keep the interaction not too complex or too simple was one of the struggles as the line between these two aspects can be hard to assess. We tried to implement this by creating something which does not require much force to interact with and that responds immediately when pressed, even when just a little. Trying to make the interaction fit these parameters was something we worked on by testing different alternatives for responsiveness. The thought of making something soft was also a result of the thought of wanting an less complex and challenging interaction. Imagining that something soft allows for interaction with not only a hand but with other parts of your body. The feedback of the evaluation with the employees pointed to that the interaction of our cushion could be fitting, with an interaction which was not too challenging. This is, however, also an implementation which would have benefited from feedback from the actual user group.

The approach we took of creating something which is more in line with a tangible object rather than a digital was inspired by the related work as well as by what we observed in the multisensory environments. Also getting the understanding that the things that could be touched and moved in a more playful way were more popular with the target group. Considering these, we believed that a tangible input device for our design could be beneficial. As we did not conduct any comparison study between digital and physical input devices but rather relied on the understandings of the employees at Eldorado as well as our own observations and gained knowledge, it can not be claimed that a tangible input device is to prefer over a digital device. However, we do believe that having something tangible to interact with can give more freedom in interaction and exploration than what a input device with a touch screen could.

8.1.1 Uncertainty Factors

Even though this project followed the intended plan as close at it could, with its intended phases, there were some factors which can be considered as uncertainty factors that could have affected in the result. Starting by considering the lack of use of the target group. At the beginning of the project, having the target group try the prototypes which we had planned to make was part of the plan. However, by the time that the prototype was ready to be evaluated, considering the mentioned pandemic that was in place, the possibility to reach our target was to be ruled out. As a solution we decided to rely on the feedback of the employees of Eldorado who had experience and insight of the target group from their daily work with them. Even if the employees of Eldorado can be considered as a more reliable source for feedback, it does not necessarily mean that the feedback can mirror the insights which could have been gained if the intended target group had been included in the evaluation. The feedback given by the employees influenced the direction which the design took, this is also an factor that should be kept in mind as the target group may not necessarily have reasoned likewise. On the other hand, we concluded that getting feedback from employees who have more experience with the target group than ourselves would be a good alternative. Working with Heuristic Evaluations with only the two of us and other designers with no deeper knowledge about the target group could have given more risk of missing factors of importance for target group.

A factor which we discussed and reflected on but which we still believe can be an uncertain factor is the way the questions for the second evaluation were asked. They were formulated in such way that they put emphasis on what the employee 'believed' that the target group could have experienced the prototype, posing questions which were grounded on the employees speculation. Despite the fact that their speculations could be more grounded in knowledge of the target group than it would have been for us, they still remain as speculations. Keeping this in mind when trying to understand the design is also of importance.

Bringing up another topic that could be one of the uncertainty factors. The Heuristic Evaluation which was made to evaluate the first prototype did only include us two designers and even though it was made after having studied the target group it could still contribute to the design taking an direction more out of line. Considering that the result of the evaluation was based on the feedback of designers only. The thought behind not evaluating with the target group was the lack of finesse in the prototype at that stage. As we got the understanding that mental imagery is something the target group can have difficulties with we wanted to get a prototype which did not require the need of imagining look and feel, interactions or responses. Finding a method to evaluate with the target group even with a low-fidelity prototype probably could have given the design an additional touch.

Something we believe to be a significant shortcoming in this projects is the fact that the evaluation of the final design did not take place, due to the various circumstances. Not having conducted this evaluation on the final design leaves us without the understanding of how the additions to it could be experienced. The design was developed further in line with the feedback from the evaluation before but not getting the chance to evaluate it again leaves us with no further knowledge of if the new implementations could live up to the feedback. Of course, a design can be evaluated several times and can always need improvements but if we would have managed to have the last evaluation, the understanding of if the design was developed in a good direction would have been clearer.

If the opportunity was given to make a project similar to this in the future, some things would have been done differently. One of the things that would have been revisited is the type of sound used for Multizen. Although a sinus wave is easy to modulate on a fine scale when you need an input sensitive control device, it does sound uniform and dull in many cases, especially during longer periods of interaction. The sinus wave was first implemented as a fast way of testing the interaction and the intention was never to use it for more than prototyping. However, as other forms of sounds were tested, including playback of sound files and notes generated from virtual MIDI synths, none of these came close to feeling as good as having a sinus wave mapped to the user input. While using sound files or midi synths have the perks of coming in a wide variety of instruments and sounds, one downside is that they both easily run into problems when playing multiple notes in quick succession. The reason why has to do with the small variations in sound that exists during the life-span of a note. As a basic example, when pressing a piano note or moving a bow over a cello string, the initial sound that arises from the first press or stroke will sound differently compared to how it sounds half a second. This results in a "jagged" sound when playing notes in quick succession. Moreover, a sinus wave allows for easy modulation of parameters such as pitch, timbre and loudness, which is useful in cases like this one where real-time user input is mapped to different properties in sound.

While on the topic of sound, one of the four themes that emerged from the usability test was a change in volume control. At the time of the test, the volume of the sound was mapped to the velocity of which the user pressed on the cushion. The velocity was calculated by normalizing the difference in pressure between the current strength and the previous registered strength value, which occurred 20 ms before (based on how fast the script was updating). This came with two problems; as the multi-sensor module had tiny fluctuations in its pressure reading, with no smoothing algorithm applied to it, the volume as a result shifted too much and too quickly that any changes to volume was hard to perceive. The other problem that arose was that once the use had reached the "bottom" of the press or squeeze, i.e. when the pressure was at its maximum, the velocity was close to zero and no sound was outputted. During the usability test, one participant commented that the level of motor activity needed in order for the user to be able to control the volume could be too high for the target group. For the final prototype, the calculation of the velocity was changed to instead use the maximum velocity during each press, meaning that from the point where the user first presses on the cushion to them starting to release the pressure again, the maximum achieved velocity would be used to alter the volume. This made it much easier to hear the changes in volume and understand the mapping between velocity input and volume changes, but it does not necessarily make it less demanding from a motor function point of view.

8.2 Ethical Considerations

As mentioned in the theory section of inclusive design (section 3.3.1.1), designers are using their prior knowledge and experience during the design process, regardless of whether they are consciously aware of it or not. This project focuses on a narrow group of users who, due to their condition, can be more vulnerable to unconscious prejudices compared to other groups. If we do not get to know the user group well enough, the issue of not knowing what is right or wrong in line with their needs and capabilities could give rise to false beliefs, i.e. stereotyping. Relating to the possibility of underestimating the target group as well, this is something we believe can be a potential issue as the capabilities of the individuals in the target group could be misjudged. As such, it becomes of great importance to analyze through the steps of the design process and evaluate how different decisions can affect the final product, the interaction and the user experience while having this potential issue in mind. Keeping a good communication with staff and caretakers can be seen as a good way to compensate for situations where it can be difficult to directly involve the target group. Due to the potential lack in communication that can arise between designers and individuals with PIMD as a result of limited verbal capabilities, it should be kept in mind that designs targeted for these individuals will always be open for questioning.

Furthermore, as an interaction designer, it is also important to think about the accessibility of your design; as an example, a majority of people with PIMD suffers from some level of motor impairment. This means that the product should be customized for gestures that do not only require fine motor skills but allows for more gross movements as well, this is in order to not exclude individuals from the experience. In the same way, the product should be designed to account for different levels of intellectual dysfunction to include as many individuals as possible, while at the same time making the product interesting enough to challenge and engage the users. To help include as many of the target group as possible these kinds of factors should be integrated in the design work to the greatest extent.

Another issue that was considered in the beginning of the project was the privacy and collection of personal data, as people with PIMD tend to have an accompanying caretaker which often are their main source of communication, it can be asked if it is ethically correct to work with information collected on a second-hand approval. Even though the closest caretakers of people with PIMD tend to have a high understanding for their likes, dislikes and communication style, understanding the true feelings of a person with PIMD can be harder. As the communication may not always be straightforward, underlying emotions can both be misinterpreted or missed entirely, or if a decision is made without the person with PIMD being involved, it can be hard to know what to classify as an actual consent. Working actively to try to understand the intentions and thoughts of the individual with PIMD is of importance, both to understand if any borders are being crossed and if the situations is being interpreted in the correct way. To avoid any unintended violation of privacy and personal data, this thesis intentionally excluded pictures, video recordings and names from the participants. Although the target group was unavailable for evaluating our prototype, the aspects of privacy were still upheld for the staff.

8.3 Future work

For future work, one thing that could be looked into would be to map the volume of the sound to something other than the velocity of the pressures. As there was no usability test of the final prototype, it is hard to estimate how demanding that specific interaction would be for the target group. In case of the volume requiring too fine of a motor skill to properly control, other options regarding the mapping can be investigated. As an example, having the volume mapped to either the accelerometer or the gyroscope of the multi-sensor module would allow for the control of volume by either rotating or moving/shaking the cushion, allowing individuals with lower fine motor skills to control the volume.

Additionally, we would also have wanted to make changes to the sound of Multizen. Giving the sound perhaps a more playful or soothing essence to it, making it into something more than a sinus wave moving in different pitches. Something we wanted to add if we would have had more time and knowledge about music synthesis, would have been the possibility to play the sounds in a cooperative way. Not just combining the sounds but making them affect each other when played simultaneously, perhaps affecting the tone, pitch, frequency or creating something entirely different in sound. Something which would spur curiosity and a positive experience from interacting with the installation in a cooperative way. Another thought regarding the music which would have been of interest to explore in future works is what kind of experience that would have been if the sound was the one of some specific instrument instead.

Other implementations which we would have wanted to work further with is the addition of cushions and their corresponding lights. We would have wanted to add at least one more cushion, following the first notion of the idea that we had. Then evaluating to see if three would have been to prefer rather than two. Moreover, improving the light patterns of the cushion is another part we would have wanted to develop. Creating more variation in the possible combinations of the colours and shapes, perhaps by adding a time aspect to the lights and a series of different combinations of the shapes. Making the lights fade, change colour or become stronger depending on how long you hold the cushion pressed, integrating a change with time. Then looking into on how relevant different shape combinations could be to help the ideation of a possible implementation.

Lastly, a thing to consider for future work is the air-proof plastic bag that is used inside each cushion. Having a sealed container is one, if not, the most essential part of an atmospheric pressure-dependent installation. If there is even the slightest of leaks in the bag, the air will be squeezed out in a couple of days and the installation will be unusable from that point. For this project, the cushions were designed to facilitate the removal of the plastic bags in case they have to be refilled or replaced. However, in an idyllic situation, one would not need to refill the bags or change them for many years. Finding a material or design that keeps the air in place during an extended period of time would be a major upgrade to an installation similar to this one.

9
Conclusion

Multisensory environments are today being used as a form of alternative therapy available for people with PIMD and are used as a method of providing a positive experience for these individuals. As mentioned by (van Delden et al., 2019), switch-like interactions are commonly used for installations in multisensory environments. However, as these systems are built around an on-off interaction, they risk offering the user less exploration and playfulness compared to more dynamic installations. In order to find out which factors to consider when designing a more dynamic installation, the following research question was asked:

Which factors should be considered when designing a multisensory installation for individuals with profound intellectual and multiple disabilities in order to create a positive experience?

In an attempt to answer the research question, a multisensory installation was designed as an addition to one of the multisensory environments available at Eldorado. The iterative process which was conducted in order to reach an answer consisted of four main phases, analyzing, conceptualizing, prototyping and evaluating. This process was done three time throughout the project, with the exception of the last evaluation of the final iteration not being conducted.

Through this process it was noticeable that there were five factors that influenced and shaped our design the most. First, as the target group can have difficulties with higher level reasoning, a clear mapping was needed in order to put emphasis on the cause and effect of the installation. The second factor regarded the implementation of stimulation of more than one sense, considering the multisensory approach. The third factor was the need of customizing the design in such way that individuals with different motor capabilities could have the opportunity to interact with the installation to the same extent. With this also comes the fourth factor, having a complexity which is on a suitable level. Not making it too difficult for the users to interact with the installation and perhaps not too easy either. Lastly, the fifth factor was the need of keeping the user engaged, having an effect which stimulates in such way that it captures and makes the user want to keep interacting.

In answer to our question, the factors that were of most importance to consider when designing a multisensory installation for individuals with profound intellectual and multiple disabilities in order to create a positive experience included:

i) Stimulating more than one sense.

ii) Customizing for different capabilities
iii) Having a clear mapping between input and output
iv) Balancing the level of complexity in the interaction
v) Having an installation that both looks and feels appealing to the user.

Although it is hard to draw any immediate conclusions regarding the target group's potential experience of interacting with the installation, based on the feedback provided by the staff members we believe that the installation could be appreciated by the intended users and a good addition to Eldorado and their work.

References

AAIDD. (2019). *Definition of intellectual disability.* Retrieved 2019-01-28, from https://www.aaidd.org/intellectual-disability/definition#.UjosLNit-VM

Ainsworth, P., & Baker, P. C. (2004). *Understanding mental retardation: A resource for parents, caregivers and counselors.*

Armatas, V. (2009). Mental retardation: definitions, etiology, epidemiology and diagnosis. *Journal of Sport and Health Research*, *1*(2), 112–122.

Benyon, D., Turner, P., & Turner, S. (2005). *Designing interactive systems.* Pearson Education Limited.

Betancourt, M. (2015, November 5). *Making music with color: How color organs connect light and sound: An object lesson.* Retrieved 2020-05-20, from https://www.theatlantic.com/technology/archive/2015/11/color-organs/414460/

Bruscia, K. E. (2013). *Defining music therapy.* Barcelona.

Buxton, B. (2007). *Sketching user experiences: Getting the design right and the right design.* Morgan Kaufmann.

Caltenco, H., Larsen, H. S., & Hedvall, P.-O. (2012). Enhancing multisensory environments with design artifacts for tangible interaction. In *International workshop on haptic and audio interaction design* (p. 45-47).

Cappelen, B., & Andersson, A.-P. (2016). *Health improving multi-sensorial and musical environments.* Conference paper. doi: 10.1145/2986416.2986427

CDC. (2019, Sep). *Facts about developmental disabilities.* Centers for Disease Control and Prevention. Retrieved 2019-01-28, from https://www.cdc.gov/ncbddd/developmentaldisabilities/facts.html#ref

Contreras, M. I., Garcia Bauza, C., & Santos, G. (2019). Videogame-based tool for learning in the motor, cognitive and socio-emotional domains for children with intellectual disability. *Entertainment Computing*, *30*.

Cox, T. (2014). *Raspberry pi cookbook for python programmers.* Packt Publishing, Limited.

Danielsson, O. (2020, March 10). *Synesthesia: A colourful ability.* Retrieved 2020-05-20, from https://ki.se/en/research/synesthesia-a-colourful-ability

Dixon, D., & Gentile, J. P. (2017). Prescribing psychotropic medication in patients with intellectual disability:review and clinical pearls. *Journal of Childhood & Developmental Disorders*, *3*(4:23). doi: 10.4172/2472-1786.100061

Eldorado. (2020). *Eldorado - aktivitet, kunskap och kultur.* Retrieved 2020-01-24, from https://goteborg.se/wps/portal?uri=gbglnk%3a201552516627

Federal Register. (2013). *Change in terminology: "mental retardation" to "intellectual disability".* Retrieved from https://www.federalregister.gov/d/2013-18552

Fitzmaurice, G. W., & Buxton, W. (1997a). An empirical evaluation of graspable user interfaces: towards specialized, space-multiplexed input. In *Proceedings of the acm sigchi conference on human factors in computing systems* (p. 43-50).

Fitzmaurice, G. W., & Buxton, W. (1997b). *Graspable user interfaces.* University of Toronto.

Foerschner, A. M. (2010). The history of mental illness: From "skull drills" to "happy pills". *Inquiries Journal*, *2*(09). Retrieved from http://www.inquiriesjournal.com/articles/1673/4/the-history-of-mental-illness-from-skull-drills-to-happy-pills

Ghoshal, M. (2019). *What is a psychotropic drug?* Retrieved 2020-02-20, from https://www.healthline.com/health/what-is-a-psychotropic-drug

Goldbart, J., & Caton, S. (2010). *Communication and people with the most complex needs: What works and why this is essential.* Mencap.

Goudeseune, C. (2002). Interpolated mappings for musical instruments. *Organised Sound*, *7*(2). doi: 10.1017/S1355771802002029

Guest, P. C. (2017). *Biomarkers and mental illness.* Copernicus, Cham. doi: https://doi-org.proxy.lib.chalmers.se/10.1007/978-3-319-46088-8

Hanington, B., & Martin, B. (2012). *Universal methods of design: 100 ways to research complex problems, develop innovative ideas and design effective solutions.* Rockport Publishers.

Hardy, J. (2015, Mar). *A beautiful mind: The history of the treatment of mental illness.* The History Cooperative. Retrieved 2019-01-29, from https://historycooperative.org/a-beautiful-mind-the-history-of-the-treatment-of-mental-illness/

Hartson, R., & Pyla, P. S. (2012). *The ux book - process and guidelines for ensuring a quality user experience.* Morgan Kaufmann. doi: https://doi.org/10.1016/C2010-0-66326-7

Hessels-Schlatter, C. (2002). A dynamic test to assess learning capacity in people with severe impairements. *American journal of mental retardation*, *107*(5), 340-351. doi: 10.1352/0895-8017

Hooper, J., Wigram, T., Carson, D., & Lindsay, B. (2008). A review of the music and intellectual disability literature (1943-2006) part one–descriptive and philosophical writing. *American Music Therapy Association*, 66 - 79.

Hooper, J., Wigram, T., Carson, D., & Lindsay, B. (2011). The practical implication of comparing how adults with and without intellectual disability respond to music. *British Journal of Learning Disabilities*, *39*(1), 22 - 28.

Hornecker, E., & Buur, J. (2006). Getting a grip on tangible interaction: a framework on physical space and social interaction. In *Proceedings of the sigchi conference on human factors in computing systems* (p. 437-446).

Hunt, A., & Wanderley, M. M. (2002). Mapping performer parameters to synthesis engines. *Organised Sound*, *7*(2), 97 - 108. doi: 10.1017/S1355771802002030

Hussung, T. (2016, Oct). Retrieved 2019-01-29, from https://online.csp.edu/blog/psychology/history-of-mental-illness-treatment

International Organization for Standardization. (2019). *Ergonomics of human-system interaction – part 210: Human-centred design for interactive systems.* (ISO Standard No. 9241-210). Retrieved from `https://www.iso.org/standard/77520.html`

Jense, A., & Leeuw, H. (2015, May). Wambam: A case study in design for an electronic musical instrument for severely intellectually disabled users. In *Proceedings of the international conference on new interfaces for musical expression* (pp. 74–77). Louisiana State University.

Kelley, T. (2001). *The art of innovation: Lessons in creativity from ideo, america's leading design form.* Doubleday.

Kircher, A. (1650). *Musurgia universalis. 1650.*

Lee, D. G., & Harris, J. C. (2004). *Intellectual disability: Understanding its development, causes, classification, evaluation, and treatment.* Oxford University Press.

Lifshitz, H., Weiss, I., Tzuriel, D., & Tzemach, M. (2011). New model of mapping difficulties in solving analogical problems among adolescents and adults with intellectual disability. *Research in Developmental Disabilities*, *32*(1), 326-344.

Lotan, M., & Gold, C. (2009). Meta-analysis of the effectiveness of individual intervention in the controlled multisensory environment (snoezelen) for individuals with intellectual disability. *Journal of intellectual and developmental disability*, *34*, 207-15. doi: 10.1080/13668250903080106

Luhtala, M., Kymäläinen, T., & Plomp, J. (2011). Designing a music performance space for persons with intellectual learning disabilities. In *Proceedings of the international conference on new interfaces for musical expression* (pp. 429–432).

McLean, A. (2009, March 24). *Mary hallock-greenewalt.* Retrieved 2020-05-20, from `https://slab.org/mary-hallock-greenewalt/`

Microsoft. (2016). *Inclusive.* Microsoft Design. Retrieved 2020-02-10, from `https://www.microsoft.com/design/inclusive/`

National Institutes of Health. (2018). *Intellectual and developmental disabilities.* Retrieved 2019-01-28, from `https://archives.nih.gov/asites/report/09-09-2019/report.nih.gov/nihfactsheets/ViewFactSheet34ef.html?csid=100&key=I#I`

Norman, D. (2013). *The design of everyday things.* Basic Books.

Obrenovic, Z., Abascal, J., & Starcevic, D. (2007). Universal accessibility as a multimodal design issue. *Communications of the ACM*, *50*(5), 83-88. doi: 10.1145/1230819.1241668

OCAD. (2013, December). *What is inclusive design.* Retrieved 2020-02-10, from `https://idrc.ocadu.ca/about-the-idrc/49-resources/online-resources/articles-and-papers/443-whatisinclusivedesign`

Pagliano, P. (1998). The multi-sensory environment: An open-minded space. *British Journal of Visual Impairment*, *16*(3), 105–109. doi: 10.1177/026461969801600305

Pagliano, P. (1999). *Multisensory environments.* Abingdon: David Fulton Publishers.

Pedersen, S. S. (2013, March). *Porter/duff compositing and blend modes.* Retrieved

2020-05-20, from http://ssp.impulsetrain.com/porterduff.html

Poquérusse, J., Azhari, A., Setoh, P., Cainelli, S., Ripoli, C., Venuti, P., & Esposito, G. (2018). Salivary $\alpha - amylase$ as a marker of stress reduction in individuals with intellectual disability and autism in response to occupational and music therapy. *Journal Of Intellectual Disability Research: JIDR*, *62*(2), 156 - 163.

Preece, J., Rogers, Y., & Sharp, H. (2015). *Interaction design - beyond human-computer interaction.* John Wiley & Sons Ltd.

Proske, U., & Gandevia, S. C. (2012). The proprioceptive senses: their roles in signaling body shape, body position and movement, and muscle force. *Physiological Reviews*, *92*(4), 1651-97. doi: 10.1152/physrev.00048.2011

Redström, J. (2008). Re:definitions of use. *Design Studies*, *29*(4), 410-423. doi: https://doi.org/10.1016/j.destud.2008.05.001.

Richard, N. P. (1990). *Quality health care for people with developmental disabilities: A guide for health professionals.* Retrieved from https://eric.ed.gov/contentdelivery/servlet/ERICServlet?accno=ED329085

Rickson, D., Evans, A., Claydon, N. R., Dennis, P., Cree, D., Dovey, K., . . . Watkins, E. (2014). *Active music.* Wellington, N.Z: New Zealand School of Music & IHC NZ.

Roeleveld, N., & Zielhuis, G. A. (1997, Feb). The prevalence of mental retardation: a critical review of recent literature. *Developmental Medicine & Child Neurology*, *39*(2), 125–132. doi: 10.1111/j.1469-8749.1997.tb07395.x

Roemer, M., Verheul, E., & Velthausz, F. (2017). Identifying perception behaviours in people with profound intellectual and multiple disabilities. *Journal of Applied Research in Intellectual Disabilities*, *31*(5), 820-832. doi: https://doi.org/10.1111/jar.12436

Shaer, O., & Hornecker, E. (2010). Tangible user interfaces: past, present, and future directions. *Foundations and Trends® in Human-Computer Interaction*, *3*(1-2), 4-137.

Sheehan, R., Hassiotis, A., Walters, K., Osborn, D., Strydom, A., & Horsfall, L. (2015). *Mental illness, challenging behaviour, and psychotropic drug prescribing in people with intellectual disability: Uk population based cohort study.* Retrieved from https://www.bmj.com/content/351/bmj.h4326

Socialstyrelsen. (2020). *Identifiering av riskgrupper som löper störst risk att drabbas av ett särskilt allvarligt sjukdomsförlopp vid insjuknande i covid-19.* Retrieved 2020-05-21, from https://www.socialstyrelsen.se/globalassets/sharepoint-dokument/dokument-webb/ovrigt/identifiering-av-riskgrupper-covid19.pdf

Story, M. F. (1998). Maximizing usability: the principles of universal design. *Assistive Technology*, *10*(1), 4–12.

Tassé, M., & Grover, M. (2013). American association on intellectual and developmental disabilities (aaidd). In (p. 122-125). doi: 10.1007/978-1-4419-1698-3_1820

Ullmer, B., & Ishii, H. (2000). Emerging frameworks for tangible user interfaces. *IBM systems journal*, *39*(3.4), 915-931.

van Delden, R. W., Wintels, S. C., van Oorsouw, W. M. W. J., Evers, V., Embregts, P. J. C. M., Heylen, D. K. J., & Reidsma, D. (2019, Mar). Alertness, movement, and affective behaviour of people with profound intellectual and multiple disabilities (pimd) on introduction of a playful interactive product: Can we get your attention? *Journal of Intellectual & Developmental Disability*, 1–12. doi: 10.3109/13668250.2018.1537845

Van Den Hoven, E., Frens, J., Aliakseyeu, D., Martens, J.-B., Overbeeke, K., & Peters, P. (2007). Design research & tangible interaction. In *Proceedings of the 1st international conference on tangible and embedded interaction* (p. 109-115).

van Wee, B. (2016). Accessible accessibility research challenges. *Journal of Transport Geography*, *51*, 9–16. doi: 10.1016/j.jtrangeo.2015.10.018

Verlenden, J. V., Bertolli, J., & Warner, L. (2019). Contraceptive practices and reproductive health considerations for adolescent and adult women with intellectual and developmental disabilities: A review of the literature. *Sexuality and Disability*, *37*(4), 541–557. doi: 10.1007/s11195-019-09600-8

Wadsworth, Y. (2011). *Do it yourself social research.* Left Coast Press.

WHO. (2007). *Atlas: global resources for persons with intellectual disabilities: 2007.* Geneva, Switzerland: WHO Press.

Wilson, C. (2013). *Brainstorming and beyond: A user-centered design method.* Morgan Kaufmann.

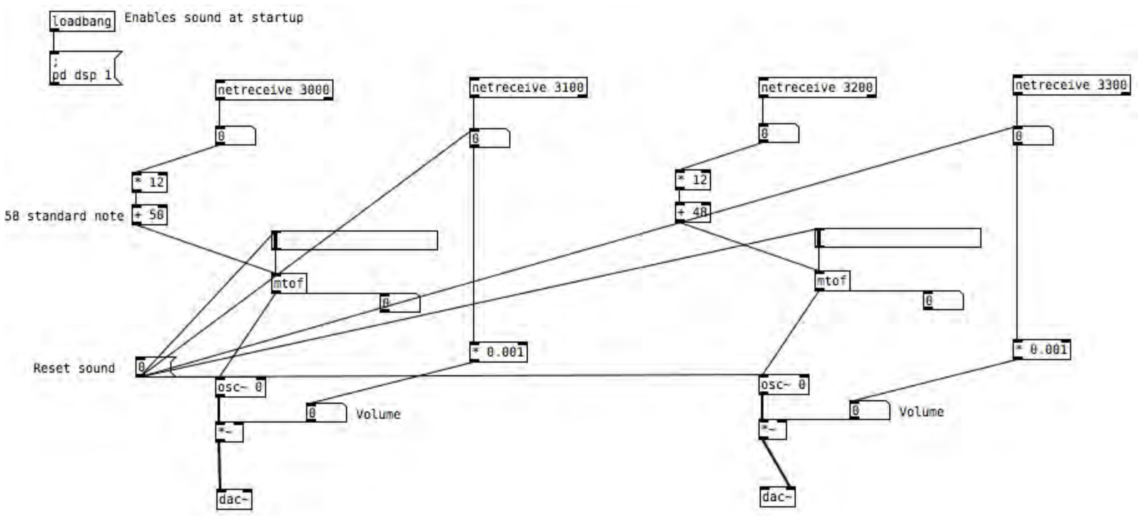
Zablotsky, B., Black, L. I., Maenner, M. J., Schieve, L. A., Danielson, M. L., Bitsko, R. H., ... Boyle, C. A. (2019). Prevalence and trends of developmental disabilities among children in the united states: 2009–2017. *Pediatrics*, *144*(4), e20190811. doi: 10.1542/peds.2019-0811

Zahra, S. A. (2019, May 10). *Accessibility principles.* Web Accessibility Initiative (WAI). Retrieved 2020-02-12, from `https://www.w3.org/WAI/fundamentals/accessibility-principles/`

A

Appendix A

Below is the PureData patch that was used for the sound processing. For more information on how it was used, see section 6.5.3.



B

Appendix B

Below is the google form with the questions posed during the evaluation of the second prototype. As the interviews were carried out in Swedish, so too is the interview questions.

User Test 1

Vi tänker oss att du ska få börja med att interagera med installationen så länge som du känner för medan vi ställer några frågor till dig angående din upplevelse och vad du tycker och tänker om installationen.

Alla åsikter och synpunkter är välkomna, oavsett positiva och negativa. Alla synpunkter kommer hjälpa oss i att förbättra vår installation.

Vi kommer anteckna det du säger, men detta sker självklart anonymt.

Låter det bra?

1. Är det en interaktion som du tror användargruppen hade uppskattat?

2. Tror du att användargruppen hade förstått sig på relationen mellan klämmandet, ljudet och ljuset?

3. Tror du att interaktion blir en rimlig utmaning för användargruppen?

4. Hur stimulerande tror du att installationen hade varit för användargruppen?

5. Vad är ditt helhetsintryck av interaktionen?

6. Finns det något du hade velat lägga till till installationen?

7. Har du några andra tankar eller åsikter gällande installationen?

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