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Visual Art for the Visually Impaired:

Designer-User Interactions in Developing 3D-Printed Tactile Models to Facilitate Access to Museum Art

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Zabrina Khan, BSc

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Introduction

My very first encounter with 3D printed relief pictures was during a hot summers day in Madrid at the Museo del Prado in their new exhibition 'Hoy toca el Prado' (Touching the Prado). Designed with blind visitors in mind, the exhibition allows visitors to access six of the most characteristic paintings of Museo del Prado through touch. Using a technique called Didú, Estudios Durero, a creative studio involved with data image engineering and graphic arts, produced six relief pictures of iconic paintings from Greco, Goya, Velázquez as well as a Mona Lisa believed to be painted by an understudy of Leonardo da Vinci. It was not the first time I had heard about the application of 3D printing to translate 2D images as I was already interested in a similar project that the Kunsthistorisches Museum in Vienna was involved in. However, it was the first of its kind to be opened to all visitors, from sighted to visually impaired and an exhibition that I was able to participate in.

Found in the North Gallery of the Ground Floor, Hoy toca el Prado, could be easily missed by most visitors that want to explore the museum in its entirety. Tucked away in the corner of the north gallery, I would not have found the small exhibition if I was not in fact looking for the exhibition.

When entering the exhibition, a long and narrow hallway covered in white walls on one side and large windows on the other, you are first greeted by a stand with hand sanitizer and pamphlets with information on the exhibition in both braille and Spanish (however not English). Along with these pamphlets, were also cardboard opaque glasses available to allow sighted visitors to try and experience the paintings through only touch. For myself personally the exhibition confronted me with what I often take for granted when experiencing a museum visit. There are not many moments where I stop and think about what it would be like to be visually impaired or blind (however throughout this research project I found myself pondering the situation more and more). It is impossible for me to truly understand what it is like to live in this society, a society that highly values the ability to see, without sight. As as sighted person, I also enjoy my regular visits to museums around the world but have never considered what these visits may be like without my sight. So to have this option at the exhibition to somehow step into what it could be like for a blind visitor was extremely confronting yet fascinating.

Using the 3D relief pictures for the first time, there were a number of issues I had to deal with in order to experience the art through touch alone. As I was not accustomed to using my hands to understand such detail, it was difficult to actually 'see with my hands'. When eventually looking at the relief picture I was touching, I found that what I was imagining or picturing in my head was completely different to what was revealed to me when I took off the blinders. However, this could also be due to my lack of practice and skill in using my hands. The first time approaching the relief painting without sight was very overwhelming. I didn't know where to place my hands, how to navigate through the painting and realised that I needed much more information than what I could gather from my hands to understand the painting even a little bit. When finally, I was given oral description and was talked through the painting, the image made more and more sense in my head. After the second or third time, this process got a little bit smoother and I was able to identify faces and distinct textures such as grass and hair. As a sighted person, after these sessions of touching I was able to open my eyes and compare the image of what I saw in my head to what I saw in front of me. Surprisingly, there were interesting moments where my mind created visual information that was neither gathered through touch or through the oral description. One example was when I was touching a dress in a portrait and automatically assuming the colour of the dress and then to be shown when opening my eyes that the dress was an entirely different colour.

This encounter with the relatively new technology started a train of thought and investigation that ended up turning into a fulfilling and fascinating research project. I was fortunate enough to find a similar project in Vienna, where a visual computing research institute together with the Kunsthistorisches Museum were collaborating in developing a similar process to the one I experienced in Museo del Prado. In an attempt to come to more of an understanding about how the technology is made, how that process looks like and how the technology is perceived not just by the different users but also the developers, I prepared a case study that involved interviewing developers of this technology, test subjects and users. As well as looking into the documents and artefacts that were used and produced by the many different groups of actors that influenced the development of 3D printed relief pictures.

One of the many issues that museums and art galleries as public spaces face today, is the issue of accessibility. One of the roles of museums in society is providing access for all visitors to their exhibitions and artefacts regardless of age, education, language or disability. However, the museum as an educational institution and preserver of history has led to high-standard measures to conserve exclusive and rare artefacts, resulting in the distancing of the museum visitor from the object. This has led to Museums being established on a fundamentally visual notion. Museum experiences rely heavily on the visual sense, from observing artefacts behind glass to reading information packages off plaques and through this has established inaccessibility for the visually impaired community. Museums have so far addressed this issue with audio guides, braille description and special guided tours. However, museum culture in recent years has begun to change, acknowledging that learning experiences can be improved through accessing knowledge through the other senses. For the visually impaired community, there has been an emphasis on touch. Nonetheless, allowing access to touch can be difficult, and often prohibited, especially when dealing with fragile and priceless artefacts that are stored for conservation. This case study focuses on a technology that addresses this issue: 3D printed tactile paintings. This technology and 3D printing in general is creating a lot of excitement in the museum community, opening doors to the possibility of touch to not just the visually impaired but all visitors.

In partnership with the Kunsthistorisches Museum (KHM) in Vienna, VRVis (Virtual Reality und Visualisierung Forschungs-GmbH), a visual computing research group based in Vienna, has developed a process in which 2D artworks such as paintings are translated to produce 3D haptic images, especially for the visually impaired visitor. Using these settings and also looking at the different actors that are involved in these settings, I will trace these different emerging observations to answer the question:

> *How do researchers at VRVis develop tactile models involving different kinds of users? And how do the users involved in the process perceive and affect the resulting technology?*

Using STS approaches, this thesis focuses on how this technology was developed, the design practices, the user imaginaries that were present during development, how the users were involved in the process of development, how the context of disability influenced the design process and how the designer overcomes the obstacle of designing for a user group that they are not a part of. Borrowing from analytical approaches in STS literature that deal with designer-user relations such as '*practice bound imaginaries'* by Hyysalo (2006), I will add to this strand of literature by exploring a new arrangement of designer-user interactions present in this case study. This technology is situated in a very fascinating context that finds the developer in a unique situation that has not been explored in STS, where they are designing for a specific group that they themselves can not subscribe to or experience, resulting in a very interesting self-awareness on their dependence on user input during the development phase. This self-awareness creates a design atmosphere that is unique and highly reliant on user feedback and dialogue. I argue that this unique case study and the complex task of translation that is involved in it, has resulted in a new way for designers to not only conceptualize users but interact with them. This technology is also surrounded by a number of interesting subjects such as translating data into representations, disability as a social issue and its impact on design practices over the years and accessibility through technology. I will conclude that not only does a unique constellation of designer-user interactions emerge, but through designing this technology, so to does a paradox of access emerge, that comes from mediating access for the visually impaired community rather than directly providing first-hand access to the visual art community.

Thesis Structure

Before diving further into the theoretical parts of this thesis I will first outline how this thesis is structured and the following chapters you will encounter in this thesis. The first half will be dedicated to discussing and presenting the research design, including relevant literature and theories that surround the context of the research, the case description, as well as the research question and methodological approaches. The second half will be devoted to discussing the observations and findings of my research, followed by my conclusions and their resulting effects.

In Chapter 1, the state of art first will be presented. It will elaborate on the context of the case study, first by introducing the museum and its role in society as well as the accessibility issues found within them and how museums have addressed these issues previously. This will then lead to the introduction of 3D printing as a technology that is being applied in a number of areas within this context, including a brief description of what 3D printing is. It will then go over literature focused on disability and how STS literature has addressed disability in the past including descriptions of few different design practices that were inspired by disability theory. This will be followed by a section dedicated to explaining different representations such as visualisation and tactilization and also briefly explain sense hierarchy and how this relates to the case study. Finally, the state of the art will finish with a section on how users are conceptualized in design practices following STS literature that focuses on their roles in design.

In Chapter 2, the research questions will be introduced and discussed in detail, including the main research questions as well as several sub-questions. The reasoning behind why these research questions were used for the investigation will be explained in this section. The case study will be described in depth with details into how the case study was assembled, along with description of the research field,

In Chapter 3, the construction of the case study will be introduced. First, a description of research field, including a brief description of the different groups of actors that have come to play in the development of the 3D relief pictures in the local network in Vienna. The methodological approaches will then be discussed including methods used for analysis.

In Chapter 4, the analysis will be discussed in two main sections. The first focusing on the developer of the technology including details on how the technology was made, the relationship between the developer and the users during development as well as the challenges and obstacles the developer faced in translating 2D paintings and producing the 3D printed tactile paintings. The second half will focus on the test subjects, their role in the development of the technology, specifically how they contributed to the design process and how they view the technology in general and in relation to their disability.

The final chapter, Chapter 5, is where I will conclude this thesis by discussing my own personal experience researching this case study as well as comment on a number of observations and findings that were made in the analysis. I will also discuss how the developer and test subjects influenced each other and consequently the design process. I will also go into detail about how disability influenced the design process and how different forms of access are valued differently by the users. Finally, I will provide the reader with further questions about the initial aims of the technology: *How far can this translation go? And did the developer achieve the translation that he set out to achieve?*

1. State of Art

1.1 Museums and access to art: 3D printing as a bridge to access

Since their beginning as mere collections of valuables for the social elite, the role of the museum in society has evolved over the centuries and has become a significant part in shaping and producing the knowledge presented to the public in certain areas such as art, history and science just to name a few. From the time when museums were first opened to the public during the 18th century, many view museums as fundamental and potentially very powerful institutions that shape the way publics understand their world and what histories are told to the public and future generations (Cairns & Birchall, 2013). Museums today are defined as by the International Council of Museums as *'a non- profit, permanent institution in the service of society and its development, open to the public, which acquires, conserves, researches, communicates and exhibits the tangible and intangible heritage of humanity and its environment, for the purposes of education, study and enjoyment'*[1].

With such a broad definition, museums are designed in a way to be 'of everyone and for everyone' with large visitor and audience reach. However, though museums have catered for a large majority of the public, there are still debates within the museum community about accessibility and how museums have presented themselves traditionally. Museums are not only involved in the responsibility of collecting, caring and preserving society's most valuable artefacts, which one could say makes them quite political. They are also involved with communicating knowledge to publics (Roberts, 1997), producing knowledge through research and documentation (Hooper-Greenhill, 1992), representing certain communities and identities from a national level to a local level. Additionally they have been linked to citizenship making and responsible for remembering and forgetting histories in deciding what stories will be told in exhibitions and thus influencing future knowledge (Bennett, Trotter, & McAlear, 1996).

Traditionally, museums have been seen as sites where engagement evolves around the collection of objects or 'things' that are presented by the museum. The many roles that museums perform mainly involve objects from their acquisition and preservation to their curation and display. However, as the role of museums evolved from collections of objects to places of conservation and preservation, some have argued that learning in museums is

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[1] In paragraph 3 of - ICOM. (2007, August 24). International Council of Museums: Museum Definition. Retrieved January 2, 2016, from http://icom.museum/the-vision/museum- definition/

no longer object-based but more textually based as artefacts are increasingly distanced from the visitor. Sandra Dudley in "Materiality Matters: Experiencing the Displayed Object" (2012) and "Museum Materialities: Objects, Engagements, Interpretations" (2009) argues that museums need to stop overlooking the materiality and physicality of objects, as these sensory elements are equally significant in experiencing, engaging and connecting with objects and things. Dudley uses a variety of examples from different exhibitions that she has experienced to come to the conclusion that how museums treat objects and things can be done differently for the benefit of the visitor's experience.

> *"My argument is that frequently, museums and visitors alike are so concerned with information- with the story overlying the physical thing- that they can inadvertently close off other, perhaps equally significant potentials of things. Specifically, they close of the potential to produce powerful emotions and other personal responses in individual visitors as a result of physical, real-time, sensory engagements. We are sometimes missing a great deal if we ignore the power of the object itself."(Dudley, 2012, p. 5)*

Dudley explains that there is a dominant view in museums studies and practice that understands museums as sites of information with objects playing a part in communicating information. It is this view that sees objects as meaningless and silent unless given a context, accompanied by information or used to tell stories identified by the museum as relevant and worth telling (Dudley, 2012, p. 4). It is through this that Dudley introduces the term '*object-information package'* to describe the role that objects have in museums at present. Currently an object's significance comes only from the cultural context and meanings that overly them. Objects form part of an 'object-information package' where their role is only to illustrate or punctuate stories being told by museums rather than being potent objects 'in their own right'. Dudley goes on to mention that it is ironic that though museums are seen as very object based and centred, describing them as 'temples of objects', this logic and practice actually acts to limit the extent in which people can engage with objects and things physically and directly. Dudley goes into more detail about how objects are displayed by museums traditionally and how this automatically distances the visitors from the objects. Nowadays many artefacts for conservation reasons are kept behind glass or sectioned off by rope accompanied by signs that read 'please don't touch' or with laser alarms to prevent people standing too close, which prohibits direct contact between the objects and visitors. Before museums evolved into these places of conservation and preservation, Dudley describes reading a recount of a museum visitor in

1706, in which the visitor mentioned that they were taken by surprise how light a wooden cane was that at first glance looked to be quite heavy (Dudley, 2012). Dudley argues that this kind of knowledge could not have been acquired unless the visitor was able to directly and physically engage with the object through touch. However, these sorts of engagements are hard to come by in a modern museum where learning is no longer object-based but now relies on textual information and language to tell the story. This, Dudley believes, is a dilemma for visitors in identifying meaning and context directly from the object and argues that *"Creative, material- focused, embodied and emotional engagements with objects should be a fundamental building block of the museum visitor's experience*" (Dudley, 2012, p. 7). Dudley sees this as a lost opportunity for museums by missing such a fundamental component in what makes objects and our world what they are. It can neglect how far the form and materials of objects influence us in the real world of day-to-day life and how we as society actually engage with objects and attribute meanings and values to them. Dudley wants to see the return to the materiality of the material, to focus the attention back to the objects themselves and focusing again and the possibilities of 'directly, physically, emotionally engaging with them' (Dudley, 2012). This type of learning and engagement with museum artefacts is not just beneficial for the general museum visitor but also a specific group of visitors that have limited accessibility when it comes to museums and art galleries, the blind and visually impaired.

Museums are beginning to become a space of 'access' as increased consumer culture and accountability in society are becoming more pronounced in public services. Museums are no longer a space for just the elite, scholars and specialists but are now part of a service intended for the use of all publics (Hetherington, 2000). As this culture arises, museums are making themselves more accessible, attempting to cater for all needs especially for groups such as children and visitors with specific learning needs. Museum accessibility can be defined in a variety of ways, for example features that affect physical access to museums, such as entrance without stairs, lifts, restrooms for parents to features that allow visitors to engage with the museums experience like interactive displays and audio guides. In recent times due to legislation, museums must comply with mandatory regulations that concern physical accessibility, however, as public spaces of knowledge, they often lack intellectual, cognitive and sensory access. Specifically, the visually impaired and blind community suffer from the lack of sensory access that museums offer (Handa, Dairoku, & Toriyama, 2010).

Access for these visitors often means access through audio and touch. Museums however have now started to consider the combined and complex interactions between visual, auditory, olfactory, spatial, and other aspects of the visitors' experience. Touch for example is not entirely forbidden as new exhibitions are attempting to involve a number of different senses (Levent & Pascual-Leone, 2014). There is only so much that can be experienced through sight alone and many museums are starting to understand that and incorporate that in their curating.

However, this need for touch in the museum context does not come without its difficulties, as museums are also seen as conservers and guardians of different artefacts of our history and so touch is often seen as a problematic request. For museums touch is problematic as touch can leave a mark of our presences, a film of oil or grease and over time this can be detrimental to the conservation of artefacts. One example of this is in the Ancient Egyptian section in Kunsthistorische Museum (KHM) in Vienna. This section of the museum permitted touch of the artefacts that were not behind glass, however over the years, thousands of visitors have touched these artefacts leading to many details of these artefacts being worn away and now to counteract this the KHM has enforced a no touch policy[2]. This creates a problem for groups that cannot obtain access through sight and it is this dilemma that 3D printing can help with in the museum context. Often when dealing with access, museums view visually impaired people as one unitary group. The aim of many museums is to recognise that visitors of a museum are diverse and address this diversity in their exhibitions, curations and services. However, when it comes to the visually impaired visitors, they are mainly defined by their lack of sight and not their interests or preferences in the same way the diversity of visitors as a whole are addressed. This lack of fundamental understanding of the visually impaired visitor has meant that visually impaired individuals can only visit museums in a disabled capacity and not offered the range of opportunities given to the general visitor. For example, often events organised specifically for the visually impaired are seen to be lacking in range and diversity, with teaching often aimed at a lower level in an attempt not to exclude anyone resulting in the exclusion of those who wanted more specific in-depth understanding and discussion (Candlin, 2003).

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[2] Brugger, F. (2013, April 19). Laser Detectors Protect Art Treasures at Kunsthistorisches Museum in Vienna. Retrieved March 12, 2016, from http://www.sickinsight-125online.com/laser-detectors-protecting-art-treasures-at-kunsthistorisches-museum-in-vienna/

KHM. (2011). General Terms and Conditions for Visitors to the Kunsthistorisches Museum with the Museum of Ethnology and the Austrian Theatre Museum. Retrieved January 14, 2016, from https://www.khm.at/fileadmin/content/KHM/Aktuelle_Meldungen/2011/BESUC HERORDNUNG.pdf

The visually impaired community have not been a stranger to exclusion and isolation to certain parts of society and museums are no exception. Since the 1990s it has been largely known that increasing accessibility amongst a wider population including the visually impaired, is a priority for museums. Since then there has been a number of different techniques and technologies developed to allow for a greater amount of accessibility for these visitors. Designs of museums have been pushed by not only the visually impaired community but by organizations such as Art Beyond Sight (Axel & Levent, 2003) to include floor indicators, special info points and special guides. Organizations such as Art Beyond Sight aim to make art, art history and visual culture accessible to the blind and visually impaired community. By providing art education to the visually impaired through museum visits and art making, they are given the opportunity to access the world's visual culture. Many organizations like Art Beyond Sight believe that the visually impaired community must have access to the world's visual culture if they are to participate fully in their communities and in society.

Before the application of 3D printing and the development of 3D tactile and relief pictures, different methods were used by museums and art galleries to offer access to visually impaired and blind visitors. Art Beyond Sight has documented these techniques in their multisensory art history book series (Axel, 2003). The two most common practices were specially organized guided tours and the use of Bas-relief pictures and models. While these techniques are still used today and often in conjunction with each other, there are still areas in which these techniques can benefit from the addition of 3D tactile models. Verbal description alone can be a very difficult task especially in attempting to create a mental image of the object being described, this is why often verbal descriptions will be accompanied by tactile diagrams. These tactile diagrams and BAS-reliefs are traditionally made manually with many techniques taking very long to make or not having enough detail.

One more readily available technique of making tactile diagrams is through the use of swell paper. This technique uses special paper that is put through an ink-jet printer, this is where the image will be copied on to it with carbon based inks/toners. The paper is then put through a special heater that raises the black ink, producing a slightly raised image. The second more common tactile diagrams are BAS-reliefs, which refer to models that have an image that has been slightly raised. In the past this was done in a number of ways, from using engravers to different carving techniques, which are done by hand. This lack of automation is added to the dilemma of the models' degradation over time through touch (Axel, 2003). A process that can address these issues and manufacture models quickly is one way of addressing this obstacle. It is from these techniques that 3D printing tactile paintings aims to improve on, with increased accuracy from high resolution scans and increased automation through computer aided printing.

Though these techniques above exist and most museums at the very least try to obtain tactile diagrams of some kind, there still exists the exclusion of visually impaired visitors in museums and art galleries. In *Blindness, Art and Exclusion in galleries and museums* (2003), Candlin investigates the attitudes of visually impaired visitors to the the provisions they have been provided with by museums such as special guided tours and use of bas relief models. As an amendment of the Disability Discrimination Act[3], the Special Educational Needs and Disability Order[4] was introduced in the UK starting from 2004. This amendment legally required museums and gallery educators to provide for all disabled persons and in particular facilitate access to art for the visually impaired. In light of this new coming change to the museum community, Candlin started to investigate what resources museums had already had in place and what visually impaired visitors thought of these provisions. Visually impaired visitors are regarded by museums and art galleries as one unitary group defined by their lack of sight. It was important for Candlin to research the needs of visually impaired visitors as these changes were starting to be enforced in order to change how the visually impaired community is excluded from museums and art galleries and in order for blindness to cease becoming the determining characteristic of their visits. Through many interviews with visually impaired museum visitors, Candlin comes to find that many of them, however diverse, fall into two different categories when it comes to their views on museum's response to visually impaired visitors: either they love the programs provided or dislike them thoroughly. Candlin argues that though many of the interviewees were happy with the program, it was less a reflection on the museums provisions but more a reflection on the exclusive culture of museums which have for a long time 'ensured that non-visual engagement with art and artefacts remained virtually inconceivable' (2003, p. 101). Candlin argues that though museums have started to provide 'tokenistic' style accessibility for the blind that they may flaunt for the good of their reputation and for funding applications. This is still not enough to make a museum accessible. There needs to a be an everyday understanding of the multisensory experience which needs to be applied in daily practice such as educations, gallery and exhibition design (2003). It is not enough to provide events and programs that

[3] UK Government Equalities Office. (1995, November 8). Disability Discrimination Act 1995 [Text]. Retrieved March 12, 2016, from http://www.legislation.gov.uk/ukpga/1995/50

[4] UK Government Equalities Office. (2006, February 14). The Disability Discrimination Order 2006. Retrieved March 12, 2016, from http://www.legislation.gov.uk/nisi/2006/312/contents/made

cover the bare minimum but facilitate access that allows a range of visitors with different interests and knowledge levels to be able to participate without constraints, even if these visitors are visually impaired.

> *"Only by making non visual learning routine will blind people cease to be defined primarily in terms of their blindness and be able to participate in ways that are satisfying to them as diverse individuals*". - (Candlin, 2003, p. 109)

One way this can be achieved is through 3D printing, which has the potential of changing how multisensory experiences of art exist in museums and art galleries. The use of 3D printing in museums addresses not only this specific issue and issues of accessibility, but also influences issues with conservation and research. 3D printing is starting to change museum practice with the option of creating exact 3D printed replicas of artefacts that can be touched and held by visitors without the conservation risks, giving visitors a new first hand experience.

1.1.1 What is 3D Printing?

Innovation is going through a period of change stimulated in large part by access to the Internet and visualization technologies to access ideas distributed from around the world. Now 3D printing is being applied to solidify many of these ideas that up until recently could only have existed digitally. Three-dimensional printing (3D printing) is a process in which a physical object is made from a 3D digital model. This is achieved by printing thin layers upon each other successively, layer upon layer until the entire object is created. The process first starts by creating a virtual design using Computer Assisted Design (CAD) files, these designs can be created initially through a 3D modelling program or through photographs and scans of objects already existing using 3D scanners. In creating the CAD files, the software program takes the final model and divides it into many horizontal layers depending on its size (hundreds to thousands). The 3D printer, which then starts to print layer by layer, reads the CAD file blending each layer into the previous (2D on top of 2D, 0.1mm ~) creating the final 3D object with no signs of layering. There are a variety of different methods to achieve 3D printing, with Selective Laser Sintering SLS, Fused Deposition Modeling (FDM) and Stereolithography (SLA) being amongst the most used techniques[5].

[5] Dehue, R. (2013). What is 3D printing? How does 3D printing work? Retrieved August 31, 2015, from http://3dprinting.com/what-is-3d-printing/

In particular, 3D printing and its influence on innovation in all areas has been astounding. In recent years we have seen a surge in innovation particularly in design and production which can be seen as a direct effect of 3D printing. In the article '*Materializing information: 3D printing and social change'*, Matt Ratto and Robert Ree (2012) highlight numerous key movements or trends that can be directly related to 3D printing and discuss how these trends and movements are creating social change. Firstly, through continuing development of 3D printing, new spaces in the form of online communities, 3D printing hacker spaces and more recently 3D printing shops have emerged for creation and invention. It is through companies like Makerbot who endeavoured to make a desktop 3D printer that was efficient, cheap and useable, allowing not just people in the computer industries but anybody interested to have access to this technology (Lopez & Tweel, 2014). As the technology not only decreases in size and in price, they are becoming more common for private use which has resulted in these new spaces of creation for example in private homes similar to the personal desktop printers that have been common in most homes in the last couple of decades. Not only are these places emerging in homes and schools but also emerging online where many of virtual communities and networks such as Thingiverse (thingiverse.com) and Shapeways (shapeways.com) have been formed dedicated to making 3D printing more accessible. In these virtual networks and communities anyone can have access to designs, open source hardware and contact to the places where the 3D printing can be outsourced. There are increasingly more commercial spaces available for ready-to-print designs where digital objects can be available for free or sold to any individual online. It is these environments that allow thousands of individuals to collaborate, make, showcase, sell and share their creations while interacting with and learning from others, resulting in the technology becoming more inclusive and participatory.

Secondly, these new environments have lead to more opportunities for citizen empowerment where the individual has more power over the fabrication of 3D printed objects, unlike most industrialized objects that are commercially available. Individuals now have increased access to 3D printing either through the affordability of the technology or by the increased 3D printing services that are now available online. Empowerment can be seen through the creation of custom tools for very specific tasks that would not be available otherwise, being able to visualize problems that are difficult to picture visually, expressing their own taste and individualism in their designs and adjusting, improving and extending other previous designs for their own needs and wants. These are ultimately manifestations of individual ideologies that are engaged with during creating and personalizing designs and creations (Ratto & Ree, 2012). There are still however some limitations to this empowerment such as size and certain material as many 3D printers have a limit to the size of the objects they can print and also the materials they can print with. These obstacles however result in more innovative and problem solving thinking that these communities discuss and engage with.

Thirdly, along with emerging citizen empowerment, there has been a shift in the conception of labour. As 3D printing blurs the line between what is digital and what is physical, so to is the notion of labour that surrounds them blurred. The amount of work that is required to materialize digital objects and if this work is unskilled or skilled comes into question in relation to 3D printing. The perceptions around 3D printing revolve around concepts such as 'automatic' and 'without having to do work', also the comparing of work it takes to print an object compared to the work of creating it by hand can lead to misconceptions of the actual work and skill that may be behind the processes of designing and developing these 3D printed objects (Ratto & Ree, 2012).

Finally, 3D printing has allowed access to another method of inventing where objects that are hard to transfer from concept to market reality can be easily 3D printed, breaking the barrier that was once needed in order to manufacture certain innovative products. This is especially true for 'amateur' or small scale inventors which now have the mean to side-step barriers such as getting capital investment for prototyping, mass production and corporate distribution. All these shifts and trends that have been the influence of 3D printing have created greater potential for innovation and would otherwise have been untouched (Ratto & Ree, 2012). The technology of 3D printing has been here for a very long time but it has only recently been found in the hands of the public and with this shift of context comes innovation and it is why such innovative ideas such as 3D tactile paintings have come to be developed and talked about.

1.1.2 Applications of 3D Printing in Museums

3D printing has become a technology that has been predicted to stimulate innovation and has become a life changing, society shifting technology. 3D printing has been responsible for increased innovation in fields such as industry with 3D printing being applied to all sorts of production from clothes and shoes to spare parts [6]. This innovation has also

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[6] Kazzata. (2014). Kazzata: Spare Parts Digital Supply Chain. Retrieved March 13, 2016, from http://www.kazzata.com/

National Institutes of Health, & U.S. Department of Health and Human Services. (2015). 3D-Printable Prosthetics. Retrieved March 13, 2016, from http://3dprint.nih.gov/collections/prosthetics occurred in the museum context. In the article '*3D Printing for Cultural Heritage'*(Neumüller, Reichinger, Rist, & Kern, 2014) collaborated the two organisations relevant in this case study, Artecontacto and VRVis, the authors go through the range of different applications they predict 3D printing can address in the context of museums and cultural heritage.

Firstly, in the area of reconstruction and preservation, 3D printing has been responsible for innovative leaps to occur in rebuilding and preserving many artefacts. Technology such as 3D laser scanners and 3D modelling software are used to scan and reproduce fine details of the artefacts that would have been impossible to produce any other way. Artefacts that were found destroyed or partially recovered are able to be brought 'back to life' as a way to provide visitors a unique insight of what it would have looked like in its prime. Examples of this type of application can be seen in a number of different cases being applied around the world such as the Temple Lion at Harvard's Semitic Museum. Originally the artefact was accompanied by a second ceramic lion in the temple of the ancient city Nuzi (Yorghan Tepe, Iraq), however only one now is well preserved at the Pennsylvania Museum of Archaeology and Anthropology (Penn Museum, 2016) with the fragments of the other kept at Harvard's Semitic Museum. The use of 3D scans and photogrammetry of the intact artefact allowed for the blending of these fragments. A replica was then produced with a combination of 3D printing and CNC milling, in order to provide the Semitic Museum with a complete lion for visitors to see how the original fragments would have looked like intact (Tharoor, 2013). Rare Cuneiform tablets at the Cornell University[7] have also had 3D printing applied to them in an attempt to create exact replicas of the tablets, with the aim of the project to replicate Cornell's collection of cuneiform tablets to look and feel exactly like the originals, including attempting to replicate the colour and texture of the tablets using 3D scanning, lasers and printing (Ju, 2011).

Secondly, 3D printing has been seen as another form of documentation in which collections can be replicated and used to allow schools, universities and other museums to have access to research them more directly. For museums with large collections such as the Smithsonian Institution and the British Museum, only a small percentage of the

[7] Gangjee, N., Lipson, H., & Owen, D. I. (2011). 3D Printing of Cuneiform Tablets | Cornell Creative Machines Lab. Retrieved March 13, 2016, from http://creativemachines.cornell.edu/cuneiform

museum's entire collection is actually displayed to the public with many artefacts stored[8]. By creating 3D printed replicas of these stored artefacts, they become accessible to the public without the hassle of arranging for the artefact to be moved or a model to be made manually (Neumüller et al., 2014). Museum research can also benefit from 3D printing application which can be seen in the case at Redpath Museum in Montreal Canada, who are using 3D printing to create models of the busts of ancient Egyptians. By scanning mummies, printed prototypes of the skulls and bones found underneath the mummified wrappings, these models were used to reconstruct the facial and body features without disturbing and unwrapping the mummies. The final reconstructions were then printed with the addition of hair and artificial eyes, and then exhibited in a number of different exhibitions allowing for visitors to view a more physical and 'real' model of what these people may have looked like rather than just a digital reconstruction[9].

Thirdly, 3D printing has been applied in a range of different events and activities in order to increase public outreach. A number of different museums have set up makerspaces and exhibitions that have focused on the 'do it yourself' aspect of 3D printing. The Metropolitan Museum of Art in New York organised the first 3D scanning and printing Hackathon[10], which has since paved the way for a number of museums around the world to do the same. During these events guests were invited to photograph museum objects and convert the images to 3D models, in which the digital files are collected and available through the museums websites. These events and digital databases have also started to be used as a marketing tool for museums with The British Museum and the New York Metropolitan Museums offering downloadable and printable replicas of some of their famous artefacts (Vincent, 2014).

Finally, the application of 3D printing can be used to facilitate accessibility and education in museums and art galleries. Models can be made using 3D printing techniques to provide multi-sensory access to objects that cannot be touched, either for conservation reasons or because they are too big or too small to understand as well as translate objects that do not have any tactile information such as images and paintings (Neumüller et al., 2014). This is

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[8] St. Thomas, L., & Grebenstein, E. (2011, September 1). Smithsonian Collections | Fact Sheet. Retrieved March 13, 2016, from http://newsdesk.si.edu/factsheets/fact- sheet-smithsonian-collections

[9] Lywood, V. (2011, April). The Mummies. Retrieved March 13, 2016, from http://www.victorialywood.com/The_Mummies.html

[10] Terrassa, J., & Undeen, D. (2012, May 31). Met 3D: The Museum's First 3D Scanning and Printing Hackathon. Retrieved March 13, 2016, from http://www.metmuseum.org/blogs/now-at-the-met/features/2012/hackathon

where the technology that is at the centre of this case study comes in. 3D printed tactile relief pictures are a method of converting gallery paintings into tactile models that can be used in guided tours for the blind and visually impaired visitor in either a museum or art gallery context. The aim of the research and design is to help make two-dimensional art that was originally intended for sighted people accessible for blind and visually impaired visitors. This is done by computer-aided techniques to ease the transfer process and speed up the production process. There have only been a few attempts to make a fully producible 3D printing program for this purpose, for example the program located in Vienna that this thesis focuses on and others such as the Midas Touch program[11]. The Midas Touch program which was developed by a group of Harvard students aimed at making art more accessible to the visually impaired through the use of 3D printing. The fundamental idea behind Midas Touch is to make the world of two dimensional art available to everybody, whatever their visual capabilities. "*We want to bridge the gap between the visually impaired and the visual world of art"* - Constantine Tarabanis one of the developers of Midas Touch[11]. The basic idea behind the Midas Touch Program was to add physical layers of texture on top of a two dimensional art work such as a painting, with a 3D printer. One of their main dilemmas the group had was colour. They experienced that those who have vision tend to overestimate the value of colour to the visually impaired, so in an attempt to address this, Midas Touch correlated different textures to different colours. However, in the end they found that the textual coding was not significant to their users[11]. Tarabanis and his team have already produced their first prototype, a rendition of the 1964 painting '*The Son of Man'* by surrealist painter René Magritte.

Like The Midas Touch program, the VRVis institute in Vienna, has gone in a similar direction by focusing its research on developing tactile models through 3D printing. It is their research and the development of their 3D printed tactile models that will be the focus of this thesis. Their project 'Tactile Paintings' lead by Andreas Reichinger, have similar aims to the Midas Touch Program. They realized the need for tactile models as an important tool to allow two-dimensional art to be comprehendible to the blind and visually impaired communities. Improving on techniques that museums and art galleries have used previously such as swell paper and bas-relief models, Reichinger's project aims to shift the production of tactile models from a more manual production to a computer aid design process. Allowing more automation for a faster, easier and more accurate process. This is

11 Vesanto, J. (2013, April 19). Midas Touch – Augmented Art Project for the Visually Impaired. Retrieved August 31, 2015, from http://3dprintingindustry.com/2013/04/19/midas-touch-augmented-art-project- for-the-visually-impaired/

done with the help of new developments in digital scanning and production tools such as CNC milling and various 3D printing techniques. With these new techniques museums and art galleries will be able to provide visitors with tactile models more efficiently, with less effort and with more detail.

> "*State of the art tactile diagrams (a stylized version of the painting, mostly line drawings embossed on paper) help getting an overview, but allow only a very simplified view. On the other side, handcrafted bas reliefs are very detailed and good to read, but require skilled sculptors in the fully manual creation process. We wanted to create a process that doesn't require any manual skills, and allows the creation of different tactile representations of suitable complexity, while being faithful to the original artworks." (Reichinger, Maierhofer, & Purgathofer, 2011)*

1.2 Disability, technology and design practices

In the previous sections above I have covered literature that deals with the context in which the case study of this thesis exists. In the following sections I will start to explore literature that deals with how this case study will be addressed analytically. In this next subsection, I will first introduce the different models of disability that are present in the disability studies and then expand on various STS work regarding disability and technology. Both these areas of literature are significant in understanding how disability has been conceptualized through out history and how this has changed. This will be followed by literature focusing on different design practices that have evolved from and have been influenced by these disability theories and models.

1.2.1 Models of Disability

This case study surrounds a part of society that has a long history of development which is attached to a whole society of meanings and contexts within this history. It centres around the design of a technology made for a disabled community and not only do we need to consider literature that draws attention to the design practices involved in the development of technology, we also need to focus on literature that concerns itself with disability in design, for example what models developers might use to conceptualize disability. Since the politicization of disability in the 1960s by disability activists, disability has been the subject of many politicians and policy makers. This rise in academic literature during the 1980s on the topic of disability has lead to a whole entire study and movement dedicated to it. A number of distinct models are essential to come to a full understanding of disability: the medical model (Davis, 2013; Shakespeare, 2013), the social model (Oliver, 1990), the phenomenological approach (Diedrich, 2001; Mladenov, 2014) , actor network theory (Galis, 2011) and new materialisms (Frost, 2011; Garland-Thomson, 2011).

The medical model of disability (individual model) bases its assumptions on how disability is located within the individual, with the functional limitations/ psychological losses assumed to arise from the physical disability (Oliver, 1990). The literature based on this model revolves around the medicalization of disability and the idea of curing, fixing or managing the disability/illness in order to conform to normative values (Oliver, 1990). The disability was seen to stem from the individual themselves and not as a result from social processes. This adoption of medicalization is one of the most significant and compelling social shifts to occur in the last half of the twentieth century, in particular in Western society.

In reaction to the medical model, Mike Oliver coined 'the social model of disability' in the 1980s with many disability rights activists taking up this model. This model instead identifies systemic barriers, negative attitudes and exclusion by society as the main contributing factor to disability. To the social modelists, disability is the outcome of social arrangements that work to restrict the activities of people with impairments through the erection of social barriers (Barton, Barnes, & Oliver, 2002).

Though the social model seemed to evolve from the assumptions of medicalization and looked towards the social construction of disability, this model still was seen by some as an inadequate conceptualization of disability. Through identifying social exclusion, it neglected the existence of impairments and pushed forward the assumption that disabled people are oppressed. This social theory of disability was seen as more of a tool to identify social constructions that influence disability rather than a fully worked out theory that conceptualizes disability as a whole (Shakespeare & Watson, 2001).

This lead to many disability theorists adopting the phenomenological approach, where they pushed to have this social disability model thinking reversed. As this approach did not only see social structures and arrangements as the sole element of constructing disability but also looked at how certain behaviours and experiences reproduced and held up these structures (Diedrich, 2001). For the phenomenological approach, by focusing on experiences, theorists were enabled to trace the embodied experience and understand disability in the sense of 'being' in the world.

This disability paradigm shift has resulted in two fundamental concepts that influence the way many comprehend and approach accessibility and disability. The first concept demonstrates that '*disability is a mainstream experience of being human'*, it illustrates that in one way or another everyone will experience a change in ability and that disability is not exclusively for some individuals. The second concept focuses on the phenomenological approach where disability can be seen as a contextual experience that occurs by the individual intersecting with the environment, not just the physical but also the social, communication, information and political environments[12]. That is, disability only exists through this interaction between the individual body and the environment and not just from one or the other. This disability paradigm shift has resulted in a change of how disability is seen and in turn has changed why and how access is to be created.

[12] Art Beyond Sight. (2008). Defining Accessibility - Art Beyond Sight. Retrieved September 16, 2015, from http://www.artbeyondsight.org/handbook/dat- defining-accessibility.shtml

1.2.2 Universal design

From its conception in the field of architecture by Ronald Mace (1941-98) in the mid 80s, *Universal design* can be seen as a growing paradigm that is being applied in a number of different areas from product design (Balaram, 2001) to architecture (Mace, 1985), and urban design (Steinfeld, 2011) on one hand and systems of media (Goldberg, 2001) to information technology (Brewer, 2001) and education (Nall, 2015) on the other. It was first referred to as a paradigm in 2006 by the United Nations (UN) when describing universal design in press releases after the adoption of the convention of the rights of persons with disabilities (CORD). Much of the literature surrounding universal design concerns itself with its application in new fields and areas such as the ones mentioned above, however for the purpose of this thesis I will only elaborate on its history, what it is and the principles of universal design that can be applied to technology that this case study is focusing on.

Many different areas of design are subject to certain protocols and codes that explicitly demand for minimum accessibility. However, many designers, civil rights movements and theorists ask for more. Due to two world wars, an aging baby-boomer population and advances in medicine which have seen people surviving accidents and illnesses that used to be fatal, the number of people living with a disability has increased compared to 100 years ago where individuals with disabilities were smaller minorities. This lead to a large civil rights movement era throughout the 1960s and 70s which resulted in the emergence of architectural strategies such as barrier free design. Disability activists' efforts resulted in the passage of federal legislation that aspired to protect the access of people with disability to the built environment. Barrier free design supported efforts in the architectural profession to design environments according to the spatial needs and demands of women, people of colour and people with disabilities (Hamraie, 2013). However, this wasn't enough for those concerned with more than architectural designs and another approach to design was developed. Established in the field of architecture *Universal Design,* coined by Ronald Mace, is described as the design process that goes beyond barrier-free design, striving to design built environments to be as accessible as possible to as many people as possible and making an environment functional for all people. Simply put, universal design refers to designing all products and spaces to be used by all people to the greatest extent possible, without the need of adaption or specialized design (Mace, Hardie, & Place, 1991).

In 1997, it was the Centre of Universal Design that established the basic principles of Universal design with their main aim focused on creating equality among people and improving the usability of products (Hamraie, 2013; Preiser & Ostroff, 2010). These principles are summarized in seven guidelines applicable to products, services and processes which can be seen in the table below.

Table 1- Principles of Universal Design (Edyburn, 2010; Smith & Buchannan, 2012)

Universal Design Principle	***Definition and explanation***
1. Universal and equitable use	same use between all users, identical where possible and equivalent where not, appealing to all users and avoids segregating or stigmatizing users.
2. Flexibility in use	provides choice of method of use and adaptability depending on user's needs.
3. Simple and intuitive use	easy to use regardless of user's experience, knowledge or language skills by eliminating unnecessary complications
4. Easily perceptible information	necessary information is communicated through design efficiently regardless of user's sensory abilities by providing different modes of presentation for essential information.
5. Design with tolerance for error	minimizes hazards by providing fail safe features.
6. Design with requirements of low physical effort	can be used with little to minimal effort.
7. Design with enough space for access, accessibility, approach, maintenance and use	regardless of user's body size, mobility or posture, design is appropriate size with enough space.

In the *Universal Design Handbook* (2011), Ostroff describes 'universal design' as a paradigm[13] that has evolved in various ways in different cultural contexts. This idea of

[13] As defined by Kuhn (1962), paradigms can be seen as general ways of seeing the world such as ttheoretical frameworks or system of beliefs and values. There is not usually an established set of rules but a traditional way of seeing the world that dictates what kind of work (in Kuhn's case scientific work) should be done and what kind of theories are acceptable.

universal design as a paradigm was first mentioned in 2006 when the United Nations (UN) in press releases described universal design as a paradigm shift after it adopted the convention of the rights of persons with disabilities (CORD). Ostroff throughout the chapter highlights several events that influenced the emergence of universal design as a paradigm. Focusing on two different threads, Ostroff shows the reader first how social justice and legislation measures drove the universal design paradigm, in particular in the US. Starting with the race-based civil rights case in 1954, *Brown vs Board of Education*, the ruling '*Separate is not equal'*, paved the way to society's need for equal opportunity. This concept of equality moved into the disability rights movement in the 1970s leading to legislation against discrimination based on a person's disability. Though these laws existed, building requirements were not considered during the design process but rather added later in order to pass inspection codes. Ostroff feels this type of designing that was normal back in the day emphasizes the idea of 'separate but not equal'. Universal design is a step away from this, as concepts of disability are shifting from the medical model to the social model, and designers are becoming aware that disability not only is established through the physical impairment but also from the inaccessible urban environments individuals exist within.

Furthermore, Ostroff mentions market driven responses to aging populations as a different force that is playing in the universal design paradigm. First seen in the country with the fastest aging population, Japan's government and business have seen the challenges and opportunities an aging population brings. Universal design here is fuelled by economic and social interests rather than a move for social justice. Many innovations in housing, product design and health care have come from Japan in an attempt to address their aging demographic. Through this Ostroff, highlights the significant cultural differences around the world in relation to how universal design emerged and has evolved.

1.2.3 Participatory Design

What makes the case study of 3D printed tactile models interesting is that how the technology is going to be used exactly by the visually impaired museum visitors cannot be assumed by the developer. As the main focus of the technology is to be used by users that the developer cannot assign themselves to, unlike most technologies where the developer themselves can be assumed as an imagined user. This is where the idea of users as co-creators (participatory design) comes in.

First appearing in the 1970s in Scandinavia, participatory design or user participation is an approach to design that has since been seen in a number of fields, predominantly in computer software design, architecture, urban design and product design just to name a few. Participatory design focuses on making sure that end-users[14] are actively involved in the design process of a certain product or structure to ensure that their needs are met. One reason why the approach is often implemented lies in its relation to democracy and the democratization of technologies (Gartner & Wagner, 1996; Kautz, 1996). The first instances of participatory design grew from work with trade unions in Norway, when there was a political push for industry to emulate the democratic principles that were present in society (Bjerknes & Bratteteig, 1995). It was in 1982 that the Norwegian Trade Union Federation with the Norwegian Employers' Federation signed a national agreement to increase the amount of power a worker has, to influence how and what work is performed (Gustavsen & Engelstad, 1985). It was from this push to increase workplace democracy by giving members of a organisation the right to participate in decisions that are likely to affect their work, that participatory design grew from (Bjørn-Andersen & Hedberg, 1977).

Since then participatory design has been used for a number of reasons such as improving the knowledge about the products and systems that are built as developers start to realize that users have substantial knowledge about the products and systems that they use (Bjørn-Andersen & Hedberg, 1977). Another reason why participatory design is undertaken lies in its ability to enable users to develop realistic expectations of a product or system by understanding the challenges and difficulties a designer/developer may face or the technical reasons for modifications and in doing so reduces resistance to change that users may have (Bjerknes & Bratteteig, 1995).

One article that very concisely highlights and compares different design techniques including participatory design in web design is the article '*Designing for imaginary friends: information architecture, persona and the politics of user-centred design' (2010) by* Adrienne Massanari. First introducing, *systems-centred design*, Massanari highlights this design is embedded with two major ideas, first the assumption that developers themselves are prototypical users, where the functionality and interface of the designs are fit the kind of application that the designer themselves would find useful. This is usually done unconsciously and happens when there is no commitment to understanding the ways in which their audience differs demographically, cognitively etc. (Massanari, 2010).

[14] End-user term that refers to persons or individuals that actually use the final product being developed (Massanari, 2010).

The second major idea that Massanari highlights, is that interacting with users during development is problematic, unpredictable, disordered and uncontrollable and that the developer knows best and the user is unknowledgeable. In comparison to this type of design, *user-centred design (UCD)* involves the development process focusing around the users and their practices. This type of designing involves active user participation in the form of research through interviews and usability tests, often resulting in design process that develops prototypes that are constantly being tested by users and then refined (Gulliksen et al., 2003; Massanari, 2010). However, users are still seen as poor designers that are unable to tell designers what they really want and though in UCD it is important to understand the user's interaction with a design, the designer's mindset views the user as an objects in which that designer must fit with the design. Massanari argues that there is still the notion that '*designer knows best'* who must help the poor user. Massanari then uses a quote from Clay Spinuzzi's *Tracing Genres Through Organizations: A Sociocultural Approach to Information Design*[15] *(2003)* to describe a classic trope of the user as a victim of poor design and the developer as their saviour.

> *"The worker-as-victim is portrayed as needing to be rescued by a heroic figure, an information designer. This heroic figure is enlightened, principled, and capable, and is able to employ user-centred design methods to defeat the tyrannical system and rescue the victims… the designer listens to the worker-victims, synthesizes their comments and feedback, and develops the means of their rescue" - (Spinuzzi, 2003, p. 2)*

Finally, Massanari introduces participatory design, where users are seen as co-creators. Although traditionally STS has long argued that users are co-creators/shapers of the artefacts with which they interact already (Bijker & Law, 1992; Jasanoff, 2004), participatory design approaches 'openly enlist the users as co-designers *throughout* the design process' (Massanari, 2010).

> "*Unlike traditional systems-centred design methods, participatory approaches do not perceive users as a problem to be fixed; they are, in fact, a critical source of knowledge about how they work and how the*

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15 Spinuzzi's book *Tracing Genres Through Organizations: A Sociocultural Approach to Information Design (2003),* focuses on workers who have to deal with designed information and how their interactions influenced the designed system. He argues that traditional user-centred design approaches do not take this into account.

technological systems can best support that work" (Massanari, 2010, p. 406).

Participatory design ensures user input is integrated throughout the design process and is not limited to the usability-testing phase. This approach makes deconstructing user imaginaries even more interesting. For example, where do these imaginaries come from and how do they come about and emerge?

1.2.4 Science, Technology and Disability

There have been many parallels between STS work and Disability studies that have found both studies following a similar history of concepts and thoughts. From positivist approaches to social constructivism, both disciplines have moved to postmodern conceptualisations of science, technology and disability (Galis, 2011). STS writers have noticed this and recently there has been a shift to apply STS concepts to the field of disabilities, for example in Science, Technology and Human Values' special section on STS and Disability in 2014 (Hackett, 2014). Below I will go through some of this literature and discuss how STS has addressed disability and how these works can help inform this thesis and case study.

It is widely written in STS that human performances are often mediated by technologies from telephones to personal computers, from cars to door closers. As such, these technologies, especially since the introduction of the Internet and the social shift it brought about, have begun to spark an interest in how bodily experiences and selfhood are altered by these human/machine interactions. However, how does disability influence these interactions and these experiences of the body and self? In the article '*Technology, selfhood and physical disability (2000),* Lupton explores this question through several in-depth interviews conducted with fifteen people with physical disabilities. Through these interviews Lupton identifies four different topics of discussion focusing on the type of technology used, the benefits of these technology, the relations between technology and identity and the problems with access to technology that the interviewees experience.

Lupton explains that past literature that has conceptualized the body and its relation to technology have not yet offered ways in conceptualizing bodies that do not conform to dominant notions of normality and how these may relate to technologies, as these texts assume the body to be free of illness or physical disability when mentioning the human body. By referencing Balsalmo, "*Techno-bodies are healthy, enhanced and fully* *functional"(Balsamo, 1995, p. 216),* Lupton illustrates that because technologies are conceptualized as being able to enhance our body's potential beyond normal functioning, arguably people with illnesses and disabilities potentially have even more to gain from technological enhancements compared to others (Lupton & Seymour, 2000).

> *"[Technologies are] any tools which humans use to do things either more easily or to do things that were not formerly possible without that tool. It could be really simple or really complicated like anything from a computer to a screwdriver – anything which I suppose enables us to do something with out fingers and arms and hands and eyes we just can't do. Glasses, hearing aids, all of those sorts of things" – Interviewee (Lupton & Seymour, 2000, p. 1854)*

Using elements of both social constructionist and materialist approaches, Lupton understands disability on one hand as a socio-culturally constructed phenomena and on the other hand sees that disability is also a physically lived phenomenological experience that is formed through social, political and material disadvantage (Lupton & Seymour, 2000). Lupton observes through these interviews that many of the interviewees hold technology with great significance with most of them using a broad array of technologies on a day to day basis. Generally speaking, the interviewees see technologies from communication aids to mobility technologies as ways to take control of their lives and gain independence, allowing them to engage in society that they may not have been able to do without these technologies. These technologies allow them to 'tame' the disorderly aspects of their body and hence allow their integration into society (Lupton & Seymour, 2000). However, these assistive technologies are a two-sided coin, though they provide disabled individuals with more freedom and autonomy, the interviewees did however distinguish between technologies that they thought helped them integrate into society and others that they saw as stigmatizing and marginalizing such as wheelchairs, as many of the interviewees felt that their identities were not tied to their disability *(Lupton & Seymour, 2000)*.

> *"I think it's not so much the technology as what the technology refers back to the user of the technology. That I, as soon as you pull out a long white cane, then people start to make assumptions about your level of vision, your level of intelligence or sorts of things like that, sort of indirect associations that are formed. I think the best example is something where that does not happen, like the little [electronic] business memo that I use. I have to explain to people, 'Look, I'll just take a not of this, I'm going to*

speak into my business memo'. People think 'Gee, that's really cool', you know because anyone can use that, it's not specially related to people with disability.' –Interviewee (Lupton & Seymour, 2000, p. 1858)

In the end Lupton found that though material factors of technologies remained vital in the ways that people with disabilities engage with technology as tools assisting their bodily function and contributing to their lived body experience, social construction of the meanings of technology and disability were also fundamental to the ways in which the interviewees talked about the impact the technologies had on their lives, for example stigmatizing technologies that influenced how they thought they were seen by others and whether they wanted to use these technologies or not (Lupton & Seymour, 2000). Though this paper was limited to a small sample of interviewees and not necessarily focused on the visually impaired, Lupton's work is still significant in how it addresses disability and technology, and the positive and negative aspects that the interviewees experienced with technologies. This will be relevant when addressing the development of the 3D printed tactile models and how these users perceive this technology. As the technology can be seen as a way for the visually impaired to experience art with more autonomy and independence, it may also be a technology that could become a signifier of disability, making it an interesting case to pick up where Lupton left off.

In Vasilis Galis' paper '*Enacting Disability: how can science and technology studies inform disability studies" (2011)* , Galis introduces Actor Network Theory (ANT) as a way to describe disability. Galis' suggestion on ANT and the general symmetry principle is that disability is an effect of a process of the associations in network. The ANT approach describes how actors, human and non-human, take their form and their characteristics as a result of their interactions with other actors within a network. How actors are enabled/disabled in relationships (both non-human and human).

> *"... ramps, guide lines, Braille, visual audio beacons, ramps and other aids produces disability/ability as an effect of associations between the human body and these material semiotic entities*" (Galis, 2011, p. 830)

> *"To be disabled is not only determined by the physical impairments of an individual's body but also by the interaction of the body with material and semiotic entities"(Galis, 2011, p. 830)*

By going through the historical developments of the different models of disability, Galis argues that there is an alternative way of ordering disability between models such as the medical model and social constructivist conceptions. Instead of focusing entirely on the physical impairment (medical model) or removing the entire focus from the body (social model), Galis proposes that disability does not reside solely in the body or in society and is the result of interactions between impaired bodies and disabling infrastructures/socio-culture. Galis further argues that the use of ANT can provide a theoretical framework that allows one to observe the *'multiplicity of the experience of being disabled by focusing on the interactions between the impaired body, disabling social and institutional barriers and inaccessible urban environments'* (Galis, 2011). ANT does this by identifying relationships and interactions between human bodies and non-humans, by attempting to cancel the divide between subject and object.

Along the same line as Galis, in Ingunn Moser's paper "*Sociotechnical Practices and Difference' (2006b),* Moser highlights that disability is enacted in certain differences in everyday sociotechnical practices and relations. Here, Moser does not solely focus on disability, but the *'multiple, intersecting axes of differentiation and power that people's lives are subjected to'.* These differences are embedded in everyday social situations and can appear, disappear, become actualized, significant or neutralized and irrelevant. To highlight this, Moser introduces a number of different stories and experiences gathered when interviewing disabled persons as part of an evaluation of the Norwegian government's ICT policy for the disabled. One significant story that Moser mentions is that of Dag, who lived in a local nursing home after suffering a severe brain injury caused in a car accident when he was twenty-two years old. Leaving Dag now paralysed, unable to speak and only being able to move his eyes and head and motor control in one arm. Dag's mother describes how living in the nursing home effects Dag's life especially socially as his friends rarely visit him in such a facility and the local municipality have not allowed for Dag to move to a place of his own outside the nursing home. Moser sees this a demonstration of how Dag is enacted as disabled by the nursing home, the practices within the nursing home and its physical structure (Moser, 2006b). Moser uses the story of Dag using a technical aid to whistle at girls as another intersecting axes of differentiation.

"Then she put the machine in Dag's lap. He looked up at us with a smile on his face, then looked down again and concentrated on the task. He moved his arm and hand and pushed to activate a message. Then there was a whistling sound: the machine whistles at the girls! The next time Dag pressed the pad, a voice asked if there were any nice girls around. (Moser, 2006b, p. 548)

Dag's mother mentions because of Dag's living situation, this kind of enactment of sex and gender were important to him as his masculinity and sexuality is often not recognised in the nursing home. Moser argues that through the machine Dag was able to enact and materialize his masculinity and gender, which is often overlooked due to the enactment of disability by intuitional practices and materialities such as the nursing home (Moser, 2006b).

Moser's main conclusions on the effects of different enactments of difference is that they are complex, surprising and contradictory. Gender, disability, class and race are not separate and can exist and be constructed alongside each other, interacting and interfering with one another (Moser, 2006b). They are practices in a variety of ways and only through situated practices are we able to see that clearly. This means that ability and disability are located neither within people nor society, but in the particular socio-material arrangement of relations and ordering of practices that simultaneously produce the social, the technological, the embodied, the subjective and the human. These frameworks will be helpful when exploring the interactions surrounding the development of the 3D printed tactile models, to see if and how disability may be enacted by the developer, the technology and the users.

New materialisms in the same vein as ANT found much significance in the material and semiotic entities that interact with bodies in disability, however new materialisms were more focused on the activeness of materials being used in an agentive way. Borrowed from material feminism, 'New' materialisms recognizes matter and materiality as agentive and productive and that meaning and matters co-emerge in a continuous process (Frost, 2011). This approach rethinks individuals' subjectivity in their embodied disability by calling to attention the role of inhuman forces or material in these situations. In connection with ANT, new materialisms sees that matter and materials are always entangled, allowing to define power relations more clearly (Garland-Thomson, 2011). The only concerns that arose with this approach was the loss of particular lenses or views of disability, it was easy to lose the political lens when switching from people (phenomenological approach) to bodies (new materialisms) (Garland-Thomson, 2011), as this approach ignores the embodied experience of the individual when focusing on the interactions between matter and material. This type of approach can be interesting to adopt when tracing different power relations that may emerge in the case study but not necessarily helpful in the main approach of this research.

Finally, in the article *'Disability and the promise of the technology: technology, subjectivity and embodiment within an order of the normal' (2006a),* Moser investigates the use of new technologies in the lives of disabled people in Norway, using excerpts from interviews with a man disabled by a skydiving accident, ethnographic notes from the interviews and videotaped television interview. Through these excerpts, Moser observes how the man interacts with the technologies he now uses and how these mobilize both agency and subjectivity, and hence a kind of ordering. Wheelchairs and the voice activated homes allows the man to become 'normalized' for example the electric wheelchair works like a prosthesis in order to compensate for bodily functions such as walking on legs allowing the man mobility and independence like '*normal people'* have.

> *"Has your life become totally inactive?... No, in no way. At the moment life is just beginning to take shape again. Now I finally do many things that abled people do, too: I go to the movies, I go out socializing, and I have mates. I am just starting to build my own house, and I will have my own car. Actually a lot of normal things" – Excerpt from television interview - (Moser, 2006a, p. 378)*

However, Moser argues that utilization of new technologies works '*to build an order of normal'* by turning disabled people into competent normal subjects and using technologies to compensate for individuals' disability, results in reproducing distinctions between abled and disabled and as such 'deviant' and 'normal' (Moser, 2006a). These technologies are used to make disabled individuals that do not fit into our social ideal by conforming them into *'competent normal subjects',* which arguably is how disability is established in the first place. Moser highlights that technologies that attempt to normalize a disability are reproducing the same asymmetries that they sought to undo in the beginning (Moser, 2006a).

It is clear to see that there are many different areas of disability that have been addressed by STS literature and that both disability theory and STS literature have developed in parallel with one another.

1.3 Representations: Visualization, Sonification and Tactilization

An interesting part of studying the technology of 3D printed tactile models is how the technology and developers navigate representation, by trying to answer questions like what counts as a representation. Though there is not much literature on 3D printing and the translation between 2D visual art to 3D haptic models, there is literature surrounding translating scientific data into different forms of representations from visualization to sonification which can be linked to the tactilization present in this case study. The translation of a visual image to a haptic model raises a number of questions such as, where does the visual element go in the process of translation and can a haptic image be considered in the same light as a visualization. The theme of translating data into more readily accessible representations can be traced through a number of works in STS literature. In this section I will first briefly explain the concept of '*sense hierarchy'* which relates not only to how the senses are used and approached in the sciences but also in society with links to the context of museums I have previously described. This will then be followed by a few chosen works in STS surrounding visualisation and sonification which deal with the similar questions raised when translating a visual image into a haptic model.

1.3.1 Sense Hierarchy

Since we began discussing the senses in the context of society, we began threading a common narrative around sight. Even as early as Aristotle in his Metaphysics (Ross & et al, 1925) mentions '*We prefer sight, generally speaking, to all other senses. The reason for this is that, of all the senses, sight best helps us to know things, and reveals many distinctions'*. This coupled with the degrading of the other senses such as touch, as the contact sense with its affiliation with dirt and uncleanliness, has lead to a hierarchy of sense embedded in our society. Dirty work, getting your hands dirty or jobs that require use of physical touch and hands have been deemed in society as less elevated compared to professions that do not emphasize the role of touch but more of sight, over looking procedures, reading and writing such as academia. This dominance of sight has also been influenced and maintained by the progression of visual entertainment, such as visual art, photography, film and TV and its significance in Western society. This hierarchy can also be seen in the evolution of the museum, where museums have been a place where publics can have access to knowledge through sight with artefacts behind glass and no touching involved. This however, excludes the visually impaired community and its only in recent years as museums focus more on increasing their accessibility to all of society, has the focus on visually dominance in museums begun to shift.

This idea of a hierarchy of the senses first proposed by Michael Foucault in '*The Order of Things'* (1970), can be also seen in the context of the museum. The prioritization of sight became dominant over smell, hearing and touch in the European perspective and has been adapted in museums with the 'Don't touch! Just look' attitude found in most museums. In the sciences this dominance of sight has been a result of sight emerging to be *the sense of science,* where scholars viewed sight as an objective, detached and clean sense. This shift of the preference of sight can be linked to public demonstrations of science in the earlier eighteenth century where sight was essential in communicating science. Sight was still dominant when scientific observation and self-discipline were emerging, as sight saw the distancing between *the spectator from the spectacle* and in this sense, sight became the sense of objectivity (Gergen, 1994).

This hierarchy of sense still exists in society and many have pushed for this to change, not necessarily replacing sight with another sense as the dominant sense but by re-introducing the notion of a 'democracy of senses'. This was first proposed by McLuhan (1962) in his work '*The Gutenberg galaxy: The making of typographic man',* about the effects of mass media on society. Here McLuhan concerns himself with the balance of the senses, writing that the development of textual information and the printing press has shifted the balance of the senses with sight placed above all the others (McLuhan et al., 1962).

Acknowledging this hierarchy of the sense is relevant to the theme of this case study, in a society that is largely focused on sight, communities that do not have access to this sense are immediately excluded. By addressing the dominance of sight, groups such as museums can observe how their institutions and their practices work to exclude groups such as the visually impaired.

1.3.2 Translating Data in Science

Ideally, a goal of this state of the art was to find STS literature that dealt with tactilization and translation of a visual image into a haptically accessible model. Though this was not achievable, literature that dealt with translating information to more accessible representations were abundant as well as literature covering translating from one sensory representation to another.

In Dason and Galison's *Objectivity (2007),* they follow the emergence and development of scientific objectivity through visualisations in scientific atlases from the eighteenth and nineteenth century. What they end up noticing is the development of scientific objectivity from before a recognised concept of objectivity to what scientific objectivity is understood as today. They related objectivity to 'epistemic values' [16] of the particular time, and saw that they were intertwined with the practice of producing scientific images. Through this, identifiable phases were seen, beginning with the eighteenth century where this idea of '*truth to nature'* was the concept of objectivity that had been taken up by scientific atlas makers. This idea that an image needs to capture the purity of a phenomena to the point where idealizing and correcting unreliable appearances was a norm (Strong, 2008). With the introduction of the camera and machine in the nineteenth century, a different epistemic virtue had been taken up and so to a different objectivity, *mechanical objectivity.* Restraining from human interference through mechanization and regulation, this concept of objectivity understood that nature should speak for itself. From the beginning of the twentieth century yet another shift in objectivity emerged, as scientific practices changed. As scientists started becoming established experts, they started to become trained in their own objectivity or '*trained judgement' (2007)*, leading scientists to 'see scientifically' which was needed in order to interpret and judge these mechanically produced images. Daston and Galison provide a historical timeline of scientific illustrations but also relate these practices with the current thinking of time. This is very useful to think about in relation to visualisations in the present, especially in relation to objectivity which is significant to translators converting 2D images to 3D haptic models. A certain visual image is created by the original artists whether it is a painting or a drawing, the translators in the process of 3D printing ideally want to restrict their bias and not have personal influence over the final product. However, their expertise is needed to make certain decisions and to conduct certain processes in order for the message of the original artist to be communicated.

Another helpful article is the chapter '*Social Studies of scientific imaging and visualization'* by Regular Valérie Burri and Joseph Dumit, which attentively outlines approaches to the social studies of scientific imaging and visualization (SIV) while also highlighting questions and considerations about the future of visual representations in science (2007). The chapter is organized in three topics, the production of images and how they are constructed and by whom, the engagement of the images and their role in the production of scientific knowledge as well their role in science communication and finally the deployment of these visualization and how images are travel outside of the academic

[16] Epistemic value – *"norms that are internalized and enforced by appeal to ethical values, as well as to pragmatic efficacy in securing knowledge" -(Daston & Galison, 2007, p. 40)*

community through other context such as media. For this section I will focus on their section of production and creation of visualizations. Using an example of the image processing of magnetic resonance images (MRI), Burri and Dumit highlight how the production and process of an image is the result of many different decisions, from the set up of the MRI machine, the filters and parameters to the post production of the image where the image's perspective can be change, it can be rotated, cropped and modified. Burri and Dumit argue that these decisions are not just influenced by technical and professional standards but also by personal preferences and aesthetics, emphasizing that this MRI is not a 'neutral product' but the product of *'culturally shaped negotiations'* (2007).

Finally, in Alexandra Supper's *Lobbying for the Ear: The Public Fascination with and Academic Legitimacy of the Sonification of Scientific Data'* (2012), a description of how one sensory representation is translated through another is explored . Although Supper does not deal with tactilization and haptic models, Supper's work focuses on the method of sonification and its application to scientific data. The book draws attention to a number of similar considerations that may also be found in the development of haptic models. Supper argues that if sonification wants to hold the same legitimacy as visual representations of scientific data, this can only be done through a social and cultural negotiation surrounding what makes a representation legitimate.

Sonification has a range of different methods and technologies that are used to represent data through sound. One classic example of sonification is the Geiger counter, used to detect radiation by emitting acoustic sounds. However, sonification is not often used on its own but accompanies other methods of representation such as spreadsheets of data or wavelengths of seismograms or even the EEG monitor and can be argued to assist in finding patterns in large data sets, from allowing blind scientists access to data and also at the very least, allow to free up another sense such as sight to be used to focus on something else.

What can be seen from the literature above is that they all offer arguments and ways of conceptualizing the representation of 3D printed tactile paintings. In regards to Daston and Galison, their historical work on visualization emphasises the relation between visualizations and scientific sense of objectivity. Though not entirely relevant to the case study of 3D printed tactile paintings they offer an interesting way of conceptualizing how the epistemic values of our present may be influencing how the production of the 3D printed tactile paintings, especially how the developer relies on the translation process to expel his own personal bias. Burri and Dumit, on the other hand argue that it is through these processes and production decisions made that influence the final product of the image. A number of different factors influence the production of an image resulting in an image never being a neutral product. This was useful in investigating the process of translating 2D image to 3D haptic model as it allowed myself to focus on the different decisions that occurred in the translation process and dig further into who, why and how these decisions were made. Finally, Supper offers an interesting argument for the need to legitimate non-visual representation. What makes a representation legitimate is questioned and challenged and opens up a number of different topics of interest in the case study on 3D printed tactile models. For the visually impaired user, what makes this 3D printed tactile model a legitimate representation for the 2D image that they cannot see?

As the process of the translating 2D images into 3D haptic models, starts from the conversion of a visualisation, aspects of visualisation are still embedded into the translation process. The literature provided above is essential for considering what the end product of this translation process it. Is it a visualization? Or tactilization? And are these similar? Whether you consider these entirely different from one another, what can be seen in the literature is that visualization, tactilization and sonification forms of translating data, and in that sense deal with the same considerations that come with that.

1.4 Sensitizing concepts: How STS literature conceptualizes user and user imaginaries in the design practices of technologies

How STS literature has conceptualized users in the past and present is a useful gage in understanding the role of users in design practices and the development of a technology as a whole. Below I will attempt to navigate through this past literature in order to illustrate how concepts of users have evolved and also to carve out the space where this case study and thesis will find itself in terms of conceptualizing the user.

The concept of users in STS literature is a focus that has lasted since the 1980s. There has been a number of different articles and case studies that have endeavoured to come to an understanding of their roles, their actions, and their reasoning by looking at both ends of the process: development & design and also the implementation of technologies (Jensen, 2012).

One of the first approaches to start conceptualizing and drawing attention to users was the social construction of technology (SCOT) theory. Developed in the 1980s and 90s by Trevor Pinch and Wiebe Bijker, SCOT is a framework of thinking focused on the development of technology that replaced the old view of users as passive consumers and argues that 'the technological' does not enter society in its finished form to impact society but instead that technologies emerge into societies continuous struggles and conflicts and it is this human action that shapes technology. The emergence of SCOT was one of the first frameworks to start replacing older views of users as passive consumer of technology. This past view was linked to the idea of technological determinism, which was the dominant view of technology before 1980s. Technological determinism views that the development of technology occurs outside and separate from society meaning that it is not influenced from social aspects such as economic or political influence. In saying this, technological determinism also views that technological change is what drives social change, simply put technological progress equals social progress (Wyatt, 2007). This notion of technological determinism for long time was a dominant view in relation to technology which understood because technology development occurred outside and separate from society, when a new technology was introduced to society it was assumed as a finished form of the design (Sismondo, 2010). However, Bijker and Pinch (1987) argued that this was not the case, illustrating this through historical examples of the development of the safety bicycle. This idea that efficient technological progress resulted in evolutionary social progress and the belief that there was no social interaction in technological development, did not fit with the

SCOT approach, which saw that technologies and artefacts are constantly being shaped by different obstacles and influences.

In Pinch and Bijker's book chapter '*The social construction of facts and artifacts: Or how the sociology of science and the sociology of technology might benefit each other' (1987),* they outline the concepts of SCOT by closely following the historical development of the modern day bicycle. Borrowing from Bloor's principle of symmetry (1973), they look at the acceptance and rejection of certain technologies of the bicycle throughout history by examining the successful theory and designs of the bicycle just as closely as the failed as different bicycles were regarded by different standards than they would be now. By examining these standards, many different social factors can be seen to have influence and changed how certain bicycle models were valued.

The idea that the successful outcome of the modern day bicycle or safety bicycle design out of all the bicycle designs of the twentieth century was inevitable is a notion that Pinch and Bijker challenge. It is easy to assume that it is safe, stable, efficient and fast and hence all designs before it may have been important in the development of the safety bicycle but eventually destined to be unsuccessful in comparison. However, through Pinch and Bijker's close analysis of the safety bicycle, they saw that the safety bicycle did not become successful because it was a superior design as some users found that different designs were more superior. For example, one group, young male riders found that the design of the safety bike was less desirable for their needs of style and speed, so the design did not correspond well to their understanding of a quality bike. There is no best way of designing a technology and different social groups can construct fundamentally different meanings of a technology. This is known as interpretative flexibility, as to young male riders the high-wheeled bicycle may have been the ideal bike but to the elderly and women this design was seen as 'unsafe'.

> *"In deciding which problems are relevant, the social groups concerned with the artefact and the meanings that those groups give to the artefact play a crucial role. A problem is defined as such only when there is a social group for which it constitutes a "problem"" (Bijker & Pinch, 1987, p. 30)*

> *"Interpretative flexibility is a necessary feature of technology as what a technology does and how well it performs are the results of competition of different groups' claims and therefore the good design of a product or*

technology cannot be an independent cause of its success, what is considered good design is instead the result of its success" (Sismondo, 2010, p. 99)

In a SCOT framework of thinking, the success of a technology or product is dependent on the strength, size and number of groups that takes it up and promotes it. It's meaning or definition relies on the associations that different actors make.

Introducing the term '*interpretive flexibility'*, Bijker and Pinch described that different groups in society interpret technology in different ways, by using the example of development of the safety bicycle (the model in which most modern day bicycles are designed from). In the specific case of the air tyre, different social groups had extremely different interpretations of the same technological artefact, they showed that for some people the tyre meant efficiency and more convenience in their transportation, where others saw troubles with traction and aesthetics (Bijker & Pinch, 1987). Following this idea, users were seen to advocate for some aspects of technologies while others advocated for other aspects. This lead to some users being excluded or not reflecting their interests or needs (Oudshoorn & Pinch, 2003). They then elaborated on this, arguing that there is are not just different ways a user sees or interprets a technology, but there are also different ways of interpreting how a technology is designed resulting in not just one optimal way of designing a technology. The SCOT approach has lead to much STS literature focusing on users and their roles, however criticism over SCOT exists and so too have critics responded in arguing that SCOT oversimplifies the interests of social groups. Though one of the first social science theories, its frameworks is hard to adapt to technologies developing in the present, as can only be really observed in historical examples. The case study that is used by Bijker and Pinch (1984) is quite general in terms of the conceptualization of users as it does not actually focus on the design practices but more generally on the social and cultural climates that existed during the development of the technology. This is unlike the thesis' case study as developers are very aware of the social interaction surrounding the technology as a result of the social issues of accessibility.

Another concept of the role of users in technology development that can be found in STS literature is in Lucy Suchman's '*Plans and Situated Actions'* (1987). Focusing more on the actual process of using a technology, Suchman's work is a dissertation that focused on the corporation Xerox[17] and their main problem at the time, being that to stay ahead of the competition, Xerox had to produce more versatile and complicated machines, but as a results the increasing complexity found that people had a harder time using these machines. This was not ideal for the company, as having double or triple as many features as a competitor's machine was useless if your user could only use a couple of these functions. This problem was first addressed by providing even more detailed instruction manuals but was found to overwhelm the user. The second attempt to address this issue was to use computer power to produce 'intelligent machines' that would serve as 'expert help systems', with the idea being that if the user couldn't understand the machine then the machine could be designed to understand the user and help with their tasks and functions.

Suchmann argues, that this incompatibility between the users and the machine was the result of '*a clash between the designers' idea of how plans are ideally made and executed and how they are actually made and executed in practice' (Duguid, 2012, p. 5)* and showed that the interaction between the user and the machine was not how designers first assumed. The designer's attempted to mimic 'ordinary' human interactions between the machine, ignoring and taking for granted how complex human interactions are. Suchman describes the human action as constantly reconstructed from dynamic interactions with the material and social world (Suchman, 1987, p. 70), and part of their sense making involves from drawing from a variety of different situated constraints. These actions are materially and socially embedded in their context, allowing these actions to unfold to produce and maintain meaningfulness and hence achieve 'intelligent action'. This initial push by Suchman allowed many other scholars to see the gain in observing and describing situated actions of users which of course highlights Suchman's background in ethnography. It is important to mention the context of Suchman's first conception of situated actions as it juxtaposed the current ideas of cognition and the human actions that were mentally governed. It is through Suchman's book that she argues that the cognitivist view was lacking in describing situations where humans actions were dependent on 'intelligible' technology e.g. instructions from a photocopier (1987). Suchman's ethnographic approach, though significant in the history of conceptualizing users and their interactions with technology, is quite dissimilar to the case study of this thesis, as Suchman focuses on the actual process of using a technology and the interactions that occur there, whereas this case study focuses on the actual development and design of 3D printed tactile models.

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[17] Xerox – a now global corporation specialising in document technology and business service products. Their Palo Alto Research Centre (PARC), responsible for a number of desktop computer products such as the computer mouse and desktop computing. Suchman was one of the first social scientists that was brought into their corporate research laboratories.

The third conceptualization of user that has developed from STS literature emerges from the material turn in STS and the emergence of Actor Network Theory (ANT) (Callon, 1986; Latour, 1987; Woolgar, 1990). ANT is a sociological theory that emerged through the independent works of Bruno Latour, Michel Callon and John Law and is used as a conceptual framework to explore sociotechnical interactions, processes and networks. ANT thought of as more of an approach than a theory grew out of sociology of scientific knowledge and science studies, borrowing from Kuhn's principle of symmetry (Law, 2009) and large technical systems (LTS), but can be applied to a variety of social science issues. Aa a materialist theory, ANT can be seen as an application of semiotics to social relationships, it is distinguished by the fact that actor networks contain not just people (human), but objects and organizations (non-human), which collectively are referred to as actors. It assumes that relations in networks can be both material and semiotic (Turner, Abercrombie, & Hill, 2006). The primary idea of ANT is the concept of the "heterogeneous" network. ANT claims that any actor whether person, object or organization is equally important to a social network and both human and non-human entities form associations (Sismondo, 2010) . Actors enter into these networks and it is within these networks that they are defined, named and given meaning. ANT does not to give advantage or exemption to natural or cultural descriptions of scientific knowledge, rather states that science is a process of diverse construction in which social, technical, conceptual, and textual are put together, juxtaposed, transformed and translated (Ritzer, 2004). ANT understands that things (non-human) and human do not act, but there are relations, negotiations, interactions and effects between human and non-human entities and it is in these relations that the exchanges of agency and power can be found and from this form meaning.

> *"Analytically, ANT is interested in the ways in which networks overcome resistance and strengthen internally, gaining coherence and consistence (stabilize); how they organize (juxtapose elements) and convert (translate) network elements; how they prevent actors from following their own proclivity (become durable); how they enlist others to invest in or follow the program (enrol); how they bestow qualities and motivations to actors (establish roles as scripts); how they become increasingly transportable and "useful" (simplify); and how they become functionally indispensable (as obligatory points of passage)." (Ritzer, 2004, p. 1)*

Similar to Suchman's situated actions conception, this third approach also entails analysing user practices, with the difference that this material approach does not assume the experiences or nature of the user. In the text '*De-scription of technical objects' (1992),* Akrich presents the term *inscription* to describe the process of designers and the assumptions about users (projected users) and their environments they embed and build into their technologies. Focusing more on the actual design process than the first two conceptions, Akrich provides a conception that sees the design of a technology as negotiable and emerging between the interactions of the designer, the user and the technology. Additionally she provides the term *de-scription* to describe the process in which actors (non human and human) negotiate with the 'prescribed' artefacts that are presented to them by using these 'prescribed' technologies in a way that was not imagined initially by designers, redefining 'real' uses (Akrich, 1992). Akrich provides a methodology for ANT to be used in analysis by describing how projected users and real users can be compared, by going back and forth between the projected and real user, can the actual scripts and interactions affected by the artefact be seen and analysed. By analysing the user's reactions to the design , the negotiations between the designer and the user can be seen (1992).

> "*…when the technologists define the characteristics of their objects, they necessarily make hypotheses about the entities that make up the world into which the object is inserted. Designers thus define actors with specific tastes, competences, motives, aspirations, political prejudice, and the rest, and they assume that morality, technology, science, and economy will evolve in particular ways. A large part of the work of innovators is that of 'inscribing' this vision of (or prediction about) the world in the technical content of the new object. I will call the end product of this work a 'script' or a 'scenario'. The technical realization of the innovator's belief about the relationship between an object and its surroundings actors is thus an attempt to predetermine the setting that users are asked to imagine for a particular piece of technology and the pre-scriptions (notices, contracts advices, etc.) that accompany it. To be sure, it may be that no actors will come forward to play the roles envisaged by the designer. Or users may define quite different roles of their own. If this happens, the objects remain a chimera, for it is in the confrontation between technical objects and their users that the latter are rendered real or unreal. Thus like a film script, technical objects define a framework of action together with the actors and*

the space in which they are supposed to act."- (Akrich, 1992, pp. 207–208)

These circumstances which can influence how inscription and description of the technology is performed can often be various. Predetermined settings can be ignored or used differently. The prefigured user, inscribed vision of future users, may in reality not exist and new users and uses may become visible. These moments of inscription that Akrich mentions that happen in the design process will be useful in the investigation of 3D printed tactile models, as certain moments and decisions during the development of the technology embed certain ideas that the developer has about the user and the role of both the technology and the user. What is interesting about the case study is that unlike in Akrich's above example's the developer in this case study is self-aware that these moments exist and engages in continuous dialogue about these decisions and these 'scripts' he is embedding.

These inscriptions that Akrich introduces can be seen in another example, '*Configuring the User as Everybody: Gender and Design Culture in Information and Communication Technologies'* by Oudshoorn, Roomes and Steinstra (2004). This paper provides another understanding of how designers conceptualize users. Leaning more into a feminist approach, the authors argue that gender identity of designers need to be taken into account in how design practices in ICT can prioritize male users. They introduce two different ways in which designing for diverse users can be restricted: *configuring the user as everybody* and the practice of *I-methodology.* Introducing the case study of the development of the digital city of Amsterdam or '*De Digitale Stad'* (DDS), the first publicly accessible digital city in the Netherlands, the authors show how configuring the users as everybody and focusing on heavily on user-centre design in the initial stages of development eventually was overruled in the later stages when technical decisions influenced by innovation rather than a user representation of everybody was favoured. The initial aim of the design was to provide a digital city that any one citizen could join and participate in. However this became complicated, for example in the case of public access terminals, which were designed to provide access for everyone. These public access terminals ended up becoming expensive as it took significant manpower to maintain them. This addressed further into design as the shift from configuring the user as everyone to designing for oneself, with one of the results being the removal of the public access terminals consequently only allowing individuals who had access to a computer or modem to be able to participate. In the end the digital city was no longer accessible to everyone but instead only to certain groups. It was later found that these initial design objectives would be later replaced with *I-methodology*, which refers 'to the design practice in which designers consider themselves as representative of the users' (Akrich, 1995; Oudshoorn et al., 2004).

This of course can be linked to ANT and 'scripts' mentioned above, which were first introduced by Akrich, as the use of personal experience for the designer to become the user or '*replacing their professional hat with their layman hat'*. In the example that Oudshorn et al provides many of the designers when making decisions about the software choose designs that suited their own personal preferences and aligned with their skills and competence. The designers stopped developing for computer-illiterates focusing on users that would have computer experience (Oudshoorn et al., 2004). They observed that this behaviour is often done unconsciously where they do not realise their imagined user resembles themselves. In the case of DDS, as nearly all designers were male, the use of I-methodology resulted in the design of DDS corresponding to the preferences and attitudes of male rather than female users. They developed a system based on their own preferences, abilities and learning style. Which resulted in the final product not complying with the initial goal of being for everybody but rather a select few that looked quite similar to the designers themselves, mostly male (2004).

The idea of I-methodology is very interesting in the case study of 3D printed tactile models, in which it does not apply at all. In the development of the technology as they developer is not visually impaired themselves, designing for visually impaired users prevents the developer from applying I-methodology. Instead an interesting phenomenon can be seen of a developer consciously knowing that they are unable to be experts of the use of the product they are designing. This is one of the significant areas of the case study that I would like to focus on, particularly, how this is approached and conceptualized.
The final concept of the role of users in technology design I would like to mention in detail is practice bound imaginaries (Hyysalo, 2006). In the paper *'Representations of Use and Practice Bound Imaginaries in Automating Safety of the Elderly' (2006),* Hyysalo uses the case study of novel healthcare technology for the elderly, in particular its design. The case study focuses on the early stages of development and how during this early phase the future use of the technology was represented. Hyysalo aims to bring to light that investigations into the use of technologies provide only a part of the picture when it comes to how these future uses are represented and constructed. The paper focuses on how practiced traditions of the developers play a part in how uses of a technology are constructed and represented, reiterating that 'use is not only planned, configured and indirectly assumed but also inscribed by how design models are conducted, the routine procedures that exist in these design models and the messy interactions that occur between the people and material in

these processes' (2006, p. 599). Here, Hyysalo introduces '*practice bound imaginaries' (PBI)* as 'relatively integrated sets of visions, concepts, objects and relations that are regarded as desirable relevant and potentially reliable in and for a practice and as having cognitive and motivational power for organizing this practice' (2006, p. 602). Specifically, using the example of early development of the *Wristcare* device used in healthcare which is worn and allows the monitoring of the individual, Hyysalo examined how the representations of use (user imaginary) were constructed, where they came from and why they proved to be wrong when the device was actually given to and used by actual users. Its imagined use and users were used in the design of the Wristcare watch such as what the target user age would be (between sixty-seventy years old), when the Wristcare watch should trigger an alarm and what the watch would be used for. As individuals started using the device, problems arose and these design decisions became un-black boxed leading to constant debate between the developers and the individuals using them such as caretakers about the devices reliability and how to optimise its use. The further development of the Wristcare device came about by drawing together multiple practices and professions offering a range of knowledge, insights and skills that would influence the growth of the technological concept (Hyysalo, 2006).

To investigate these interplaying practices involved in the development of the device Hyysalo describes five different facets of Practice bound imaginaries to further elaborate how PBI can be useful in examining professional practices when it comes to user-representations.

"Practice Bound Imaginaries:
1. Are bound for and bound to future practice
2. Are layered and inter-animated with other PBIs and cultural resources
3. Are bound together from norms, solutions, projections and so on
4. Are restricted primarily to a specific practice
5. Have varying memberships and are interpreted in communities of joint action"
(Hyysalo, 2006, pp. 607–608)

Through this, Hyysalo highlighted that these user imaginaries are established by the design practices of the designers and the interactions that occur in these practices. This example Hyysalo provides a helpful framework about how developers build user imaginaries and how these user imaginaries influence technology (Hyysalo, 2006). These 'design imaginaries' are conceptualized in a way that designer's user representations are located in between the multiple interactions and practices involved in the construction of a new technology. Not only is use configured and assumed in the beginning of the design of a technology but muddled interactions with users and material allow for designers to become aware of the implications of their design solutions, even if it is after their technology is reshaped by resistance of users of the technology (Hyysalo, 2006). Who the users will be, how the technology will be used and what kind of functionality will be appreciated by users are all significant questions that are addressed in these practice bound imaginaries Hyysalo describes.

By coming to understand the base assumptions of the designers and their imaginaries of their users and the technology we can start pulling away at their representations as well. Hyysalo provides a more dynamic model of how developers build this user imaginary and how this user imaginary influences the design process. Similar to Akrich (1992), Hyysalo recognizes that certain ideas of how the developer sees the use and user of the technology are scripted into these technologies in the design process. However, Hyysalo takes it a step further and argues that it is through design traditions and design practices that this user imaginary is inscribed into a technology. This not only focuses on the designer but also on the interactions that occur in these design practices including people and material. What is significant for myself to take away from Hyysalo's argument is how designers become aware of these assumptions and imaginaries, and in this case the problems with their solutions only after these 'solutions' are met with resistance and challenged by users leading to the reforming of the technology. In contrast to this, the case study that this thesis concentrates on, sees that the developer is self aware of the difficulties that he is challenged with in designing the 3D printed tactile paintings from the beginning of his process. This results in the developer's reliance on the users and their feedback before producing an artefact, therefore reducing resistance and refusal of the design and instead creating an open dialogue between developer and users about the users' needs and the possible technical solutions that he can provide.

2. Research Questions

2.1 Main Research Question

In alignment with what I have stated previously in the introduction and state of art, the main research focus of this thesis focuses around the technology of 3D printed tactile paintings. The case study as a whole is new and only recently starting to be explored but has not been addressed specifically in STS literature. As I have introduced previously, the main question of my research is as follows:

> ***How do researchers at VRVis develop 3D printed tactile models in order for the visually impaired community to gain access to art?***

This question focuses on the specific developers based in Vienna involved with creating the 3D printed tactile paintings that my research surrounds. My main aim with focusing on the developers was to get more of an in-depth understanding of how a product such as the 3D printed tactile paintings are made, what decisions are involved and who makes these decisions. By understanding the technical aspects or the nitty gritty of development I hope to highlight the narratives and underlying assumptions of different actors involved in the process such as the developers and the users/test subjects. There are a number of different challenges that the developers face in order to establish a technology for the visually impaired community in the context of translating art and understanding how this is done from a STS standpoint could be very interesting and rewarding. The technology is situated in a very unique context as it finds itself in a number of intersecting themes such as technology and art and disability and access. Additionally, my main research question allows the investigation of this case study to be opened up and further followed up by the sub-questions below, focusing on the user imaginaries, its relation to disability and the perception of the technology.

2.2 Sub Questions

Though the above main question may seem straight forward, as I have introduced in the State of the Art, there are many different conceptual areas that this case study overlaps. In order to thoroughly comprehend this case study, several themes of sub-questions have been used to investigate this case and the data gathered from it.

The role of design and user imaginaries

• *What user imaginaries are built into these tactile models?*

This question focuses primarily on the development process rather than the user experience and focuses on the imaginaries that are embedded in the technology through the developmental process. Before the technology is 'used' for the first time, the developer imagines how this user and user experience would look like and by doing this influencing how the technology is produced. Any obstacles or challenges that arise will allow the developer to think about the imagined user and make decisions in the process that will lead to the production of the final product. These user imaginaries that I want to investigate will come mainly through interviews that will be conducted with the developer and also the test subjects involved. I hope to be able to link these user imaginaries with how the technology is perceived by all actors involved and not just the developer. Addressing this question will allow more understanding about why certain decisions and steps were made in developing the 3D printed tactile paintings.

The role and the effect of the users

• *How do the users involved in the process perceive and affect the resulting technology?*

What I have found with asking the main research question and coming to understand how the technology is developed, is that it allows the investigation to get a sense of how the developers and users perceive the technology through the various stages of development. I wanted to see how this perception could influence how the technology is developed and produced. The most interesting part of what the question refers to is that the users are quite involved in the design process compared to the development of most technologies. One of my main reasons for my choice in focusing on how the users are involved in the process and how they see the technology, lies in my interest in the different types of users that influence the development of 3D relief pictures in Vienna. There is also not just one user but a couple of different users that influenced the development of the technology in their own specific way and this will be interesting to tease out. This is a unique technology that requires a certain know-how or experience that only the visually impaired user has obtained, so the role of the user in development is very significant. It is not enough to look in how the developer produces the technology but also how they engage with their imagined users, test subjects and their funders.

Disability and its influence on design

• *How does the context of disability and impairment influence these processes of innovation?*

An important element of this case study revolves around designing a technology for a part of the community that are visually impaired or partially sighted, because of this, disability as a theme and concept is very significant for understanding the context of this case study. Disability is seen by a majority of society as a deviation from the standard functioning existence, because of this many innovative designs and technologies are focused on 'fixing' a disability and bring the disabled body to a normalized functionality. How we conceptualize disability and how disability is modelled in society can very well shape how technology is designed with the disabled community in mind. By addressing this question, I hope to focus on how disability may have been enacted in the development of the tactile paintings and also how disability is addressed in these processes.

The obstacle of designing for another

•*How does the developer come to terms with designing for a user that they are unable to embody?*

One of the more interesting and challenging parts of the research question is grasping how the developer comes to terms with designing for a user that they can not embody. It is not very often that developers need to conceptualize their technology to this extent. This case study is unique in the sense that the developer is self aware from the beginning of the development that they personally are not an expert in designing for the visually impaired as they are not personally visually impaired. In most cases, developers and innovation arise through personal experiences where they are able to more or less design for an imagined user that is similar to themselves. This sub question should be quite interesting as I will be able to compare the three stories that my interviews have provided me and spotlight relevant events in interviews and compare the test subject's narratives, the developers and also construct my own narrative through this comparison.

3. The Case study: Material and Methods

3.1 Introducing the Case

In the previous chapters above, I have endeavoured to introduce a comprehensive background and theoretic framework specific for this thesis as well as the research questions that I will be concentrating on in my empirical data. In order to provide a concrete understanding of the case being investigated, the following chapter will provide information describing the case study, the tools being used to structure the research and should continue on from the research questions in guiding this case study into a focused research project. First I will describe the case and the contexts related to the case that will be significant to take into consideration, which will also include the motivations behind investigating this case. Secondly, I will offer an explanation of the methods chosen to approach collecting data and analysing said data, as well as the considerations that I made when carrying out this process. Finally, I will talk about the ethical considerations that were addressed during the project.

3.1.1 Research Field (description of the case)

As we have come to know in STS, technology does not exist in our society as a separate entity, detached from cultural, societal and political influences but is in fact embedded within these influences as a co- produced part of society (Akrich, 1992; Bijker & Law, 1992; Jasanoff, 2004). The aim of this case study is to investigate one particular technology that overlaps a number of different themes and involves a number of different actors. The technology in question in this research project is that of 3D printing in the development of tactile paintings or 3D printed depth models, which is a technology used to translate 2D art into 3D tactile translations primarily for the use by visually impaired museum and art gallery visitors. In particular, I will be looking into a localized case based in Vienna that involves a number of different actors and organizations. In this thesis I will be specifically focusing on the work done by developers at VRVis Research Centre (Virtual Reality und Visualisierung Forschungs-GmbH) in developing this translation process. However, this case study involves more than the work of the developers and starts much earlier on too. The project was mediated by the Federal Ministry of Education, Art and Culture under the initiative '*Kulturvermittlung mit Schulen in Bundesmuseen 2010'* (Cultural Education with Schools at Federal Museums 2010) and advised and organised in partnership with KulturKontakt Austria[18]. This initiative aims at increasing

[18] Schmied, C., & Husslein-Arco, A. (2015, February 19). Bundesministerium für Bildung und Frauen - Initiative Kulturvermittlung mit Schulen in Bundesmuseen - Zwischenbilanz und Ausblick auf 2013. Retrieved April 2, 2016, from https://www.bmbf.gv.at/ministerium/vp/2013/20130306.html

the use of museums as places of learning and uses financial incentives for national museums to develop new and useful educational programs. Through this funding initiative the Kunsthistorisches Museum of Vienna (KHM) was able to fund their project with VRVis in developing these 3D-printed tactile paintings. The start of VRVis involvement began in early 2010 when they were approached by the Kunsthistorisches Museum with the project to produce tactile translations of a series of their most notable artworks. The development of these tactile paintings occurred in three different phases, the first involving scanning and analysing the paintings followed by identifying important structures and features through drawing lines on scans. The second involved adding depth to these structure, using software to create a depth map of the scans. The final and third stages involves extracting textural features of the painting through scans and super imposing them on the depth maps produced before. The final product is then produced through a combination of layered printing (3D printing) and CNC (computer numerical control) milling. In total, four tactile models of three paintings were produced for the KHM, one offered to all visitors on display in one of their main galleries and the other three used in special guided tours with the visually impaired (Reichinger et al., 2011). Below I will outline the different groups involved in this case study in more detail:

VRVis Research Centre (Virtual Reality und Visualisierung Forschungs-GmbH) – Founded in 2000, VRVis is Austria's leading research institute and internationally recognised in the field of visual computing with over sixty employees working on a range of different projects that fall into their field. Additionally, it forms the largest European research cluster in this field in partnership with the technical universities of Graz and Vienna as well as the University of Vienna. The development of this software and technology to allow for the translation of 2D artworks into 3D relief pictures is only a small project that VRVis are involved in and the particular project with the KHM lasted roughly six months. However, since this project they have been continuing to research and develop this technology for a number of years, experimenting with materials and with the assistance of special test subjects who represent the end product users (the visually impaired visitors). They are an active partner for research initiatives of the federal government and also the city of Vienna, their daily agenda involves transferring technology from science to industry and they see themselves as the bridge between the two: academia and industry. Their involvement with the project of 3D printed tactile paintings started when the Kunsthistorisches Museum approached them with a research grant as they are Austria's leading research company in this field and conduct a variety of applied research for a number of different partner companies. This project's aims are parallel with the institute's aim of strengthening the innovation and competitiveness of Austria (VRVis, 2000).

Artecontacto – An organization committed to assisting members of the visually impaired community in relation to art. Based in Vienna and Barcelona, Artecontacto is an organization at bringing art to the blind and visually impaired through contact and touch using multiple senses to allow access to art and knowledge. They provide specially catered guided tours for the blind and visually impaired using a mixture of different technologies and materials including technology developed by VRVis (Artecontacto, 2012).

Bundes-Blindenerziehungsinstitut (BBI) –An organization dedicated to helping the members of the community that are visually impaired in all aspects of life. The Bundes-Blindenerziehungsinstitut (BBI) is the federal institute for the blind that provides the visually impaired and partially sighted community a range of different services that develop skills such as reading Braille, learning how to use technology and also provides a place for people to meet. Both the test subjects of the technology are affiliated with the BBI and through the organization the developer got in contact with them[19].

Kunsthistorisches Museum– also known as KHM, is the main art history museum in Vienna which houses many important artifacts and artworks primarily from the Habsburgs collection. They offer a number of different guided tours catered for a number of different groups in their accessibility program. The KHM were the ones that approached and contacted VRVis with a grant into developing a technology for their accessibility program and ultimately the ones who sort out funding for the research; in the end four tactile models were produced for them[20].

[19] BBI. (2014). Home page of Bundes-Blindenerziehungsinstitut. Retrieved April 2, 2016, from http://www.bbi.at/

[20] KHM. (2014). Home Page of Kunsthistorisches Museum Wien. Retrieved April 2, 2016, from https://www.khm.at/

Users (the visually impaired community)– Users and potential users are included in this network as the local community of blind and visually impaired who collaborated closely with the researchers through the Bundes-Blindenerziehungsinstitut and also forming the network that Artecontacto cater for. The BBI involvement with the project started when the KHM approached the BBI to translate documents about the project into Braille (a service that the BBI provides) and through this found suitable test subjects to assist the developer and the development of the 3D printed tactile paintings.

3.2 Methodological Approach

In order to address the research questions and explore the different areas and actors I have stated above, I have consulted in a number of different methodological approaches. As this is a case study that in the beginning needed to be teased out and explored, my choice of materials of analysis have been quite open. Though my data collection focuses on the use of semi-structured interviews with different people involved; video analysis, participant observation and document analysis have all been used in order to collect additional data either for analysis or for understanding the context. The reason for this multi-methods approach stems from the need to explore this case study thoroughly before even focusing on what specifically one wanted to investigate. It has only been recently that interest in three dimensional printing and user innovation has arisen, and in relation to the context of disability and museum, there has been no STS research published yet. In light of this, multiple methods held an advantage in exploring the case in its entirety. By being able to pull from many different methods, a range of principles and causation can be accessed. Even though time consuming, this approach has been valuable in order to not leave any area unseen.

The sections below will focus on three different research methods that were used, mainly interviews, with participant observation and video analysis only used to contextualize the case study. These methods will be explained in detail along with the reasons why these methods were chosen for data collecting and also the challenges that occurred while using these methods.

3.2.1 Semi-structured Interviews

Most of the data that is focused on during the analysis in the coming pages of this thesis have come from the semi structured interviews I conducted with the developer at VRVis and the developer's two test subjects at BBI. The choice of this method was directly influenced by the research question and the research focus in this case study, though the case study involved many different areas, the aim of this thesis was to focus the research suitable for a master's research project. Directly focusing on how the technology was developed and how the developer imagined the user of this technology could have lead to a number of different methodological approaches, but considering that development of the technology had already finished and that there was not too many documents and videos about the development, one of the best ways of accessing technical details and the developer's perception of the technology was through face to face time in the form of a semi-structured interview (Miller & Glassner, 2011). The interview with the developer was treated as an expert interview as there were still many aspects of the technology and the software design that I couldn't have grasped without their explanation. This choice of method would allow access directly to developers and their actions and thoughts first hand. I also conducted interviews with the two test subjects involved and it was through these interviews that I was introduced to their experience in museums and how living with an impairment influences their day to day life. These were in some way also treated as expert interviews as it was only through them that I was able to understand this unique experience. By talking with developers and test subjects I was able to get their assumptions and experiences first hand without interpreting it through documents of videos. This method is in line with my research question which is interested in narratives and imaginaries that the interviewees can describe first hand.

Interviews are broadly understood as a method of data collection, information and opinion gathering through the use of asking a series of questions and is usually understood as a social interaction of sorts. In Silverman's *Interpreting Qualitative Data (2006),* Silverman explains that there are a number of different ways or styles that an interview can take depending on context or setting, the purpose of the interview and how the interview is structured. These are mainly distinguished as *structured, semi-structured* and *open-ended* interviews, with *structured* interviews comparable to questionnaires where much preparation goes into the interview questions with the goal of creating 'pure' data and no improvisation is used during the interview. This interview strives to be 'neutral' and consistent with other interviews conducted. The second type of interview, *semi-structured* is increasingly more flexible than the structured interview, which is guided but not restricted to a set of questions prepared before hand. This type of interview encourages the interviewer and interviewee to elaborate on the questions provided. The final style of interviewing is *open-ended*, which can be viewed as the most flexible of the interview styles. This style of interviewing allows for the interviewer and the interviewee to engage in a fluid interaction, where there is no need to stick to a set of questions. This focuses on 'active listening' on the behalf of the interviewer, in order to allow the interviewee the freedom to talk and ascribe meaning (Silverman, 2006, p. 110).

For this research project, consideration not only went into what style of interviewing would be conducted but also what is to be made of the data gathered from this method. Unlike positivist views that understand that interview data possibly allow access for the interviewee to 'facts' of the world and emotionalist views that see the interview subjects as actively constructing their social worlds through the interview.

'[In reference to Interviews] Are not just a site where data is collected but a site where data is co-constructed, where identities are forged through the telling of stories and where meaning making begin' (Alasuutari, Bickman, & Brannen, 2008, p. 335).

The interview data from the three interviews conducted for this research project will follow more of a constructivist view, where it is understood that both the interviewer and the interviewee are actively engaging in meaning construction (Silverman, 2006). Even though the view of constructionism that interviews do not offer insights about the social world, other than the specific social situation in which the data is co-produced (the interview), emphasizing that interviews are mutual exchanges that are context specific and involve the interviewer and interviewee both mutually creating and constructing narrative versions of the social world (Miller & Glassner, 2011). I still believe that there is value in this mutual construction of meaning that is found in interviews and because of this, these narratives will be reflected in-depth by myself as a researcher in a final analytical chapter. It is not only the narratives of the individuals that have been interviewed that are of interest but also my own as I conduct this research project.

As mentioned previously, semi-structured interviews were the method of choice. There were several reasons and considerations behind this decision. As this was my first time ever conducting interviews for myself personally as an interviewer a set of questions to guide the interview were ideal. However, this was not the only benefit of a semi-structured interview, this style of interviewing allowed me to delve deeper into interesting parts of the conversations I had with the three individuals, especially because the focus at the beginning was quite broad, this flexibility allowed the research to flow into what it is now. It also allowed myself not to be tripped up when questions were not understood precisely or engaged with in the way I perceived it would during my preparation of the interview. I was allowed to skip questions that I thought were already addressed or not applicable and this especially was helpful for my first interview. Of course this lead to nervousness of the data I would find after the interview was over such as thoughts like 'did I ask enough questions about this topic?' or 'should I have pressed them further when they were talking about this?' but in the end this became a quite fruitful method in terms of data collection.

The first interview was conducted with the developer of the technology at his office at VRVis. Not only was this the first interview for this case study but also the first research interview I have ever conducted. If this affected the interview, I did not notice as the developer was quite well rehearsed when discussing the process of developing this technology. Not only had he done previous interviews about the technology but answered similar questions. The interview also involved demonstrations and displays of the prototypes that he produced and also a final product.

In both interviews with the test subject, I started out with trying to get to know each individual and how they got involved with the project. For both interviews I went to the Bundes-Blindenerziehungsinstitut (BBI) in Vienna where both test subjects are involved and employed. I didn't know much about the institute so part of the interview was also used to talk about what the institute does and their own individual roles within the institute.

Interviews were conducted separately with each individual in order to have time in between interviews to reflect on before conducting the next. The second interview (first with test subject) exposed to me to a few different situations that I wasn't prepared for, from when I realized that getting permission for recording the interview would not be through signing of a consent form but through oral confirmation. During the interview I started to realize that some of the interview techniques that I had learnt from the Masters seminar would be rendered useless such as nodding to persuade the interviewee to continue, smiling and how I made eye contact. I don't know why It only occurred during the actual interview that I realised all of this. I remember hoping that the interviewee could hear that I was smiling and enjoying my time learning from them. I remember before the first interview that I was silly to worry so much about the outfit I picked for the interview because they were not going to see it and I was also not going to describe it to them.

In order to gain access to the field, contact with a number of different people was made. In the case of the research developers at VRVis, initial contact was made first with organisers at Artecontacto who gladly forwarded me to the developers at VRVis. After a number of email exchanges an interview date was scheduled at the VRVis institute. This is where an hour and a half semi-structured interview was conducted. On arrival consent was provided in the form of a consent form for recording the interview and also prototypes and demonstrations of the technology were provided by the interviewee, because of this fieldwork notes were also constructed during these parts of the interview.

After transcribing and initial analysis of this first interview, a big realization that occurred for me in the project was the need to get the perspective of the visually impaired test subjects who provided feedback to the research developers while developing the technology from their first prototype to their final product. The test subjects were mentioned a few times by the developer and it became obvious that their perspective would be quintessential to coming closer to understanding the entirety of the case study and the relations within it. I planned on conducting two more interviews, separate interviews with each of the test subjects. Through contact with the developer, contact information for both test subjects were provided for me and through email interviews with both test subjects were organized. A time span of a week was provided in between these two interviews to allow myself time to transcribe and reflect on interesting areas in the earlier interview in order to prepare for the later interview.

Table 2 - Information about interviews conducted

Interviewee	**Location**	**Duration (h:m:s)**	**Recording method**	**Transcribing method**
Developer	VRVis	1:18:00	Voice Recorder	Careful Transcription (CTR)
Test Subject A	BBI	1:04:16	Voice Recorder	Careful Transcription (CTR)
Test Subject B	BBI	1:01:09	Voice Recorder	Careful Transcription (CTR)

3.2.2 Contextualizing the case study: Mix and Match approach to methods

During the early parts of the investigation, a number of different additional methods were used in order to gain data that would help contextualize the case. Several methods were used from ethnography to video analysis, though this data was not used in analysis, it did provide beneficial for setting up these interviews, writing questions and discussing with the interviewees.

Ethnography is an approach that allows researchers to intricately observe and understand different practices from the perspective of the participant and individuals under observation by being involved in the topic under investigating and through this observing. This can involve spending time watching individuals as well as talking to them in order to observe how they understand their world (Marvasti, 2003). The main method of collecting data during an ethnography or participant observation is by constructing field notes, ideally during the observation or directly after in order to be able to write down all observations and thoughts made during the observation and participation, pretty much providing a written account of their experience. This is very useful when it comes to reading, coding and analysing the data. This method of constructing field notes is obviously influenced by the person writing them as different researchers experience and describe these experiences in different ways, and hence my using the term '*constructing*' field notes and not '*taking*' to highlight my role in and influence in constructing the field notes. Other forms of data collection can be used and take form in voice or video recording but because of the nature of the observation where ideally the individuals being observed are unaware of the ethnography, this can lead to ethical concerns. Ethnography and participant observation allow the researcher to observe individuals without this concept of '*observer's effect'* which is common in interviews and refers to the idea if an individual knows they are being watched that this influences the way they act and present themselves (Emerson, Fretz, & Shaw, 2011).

During my time investigating this case study, I found myself drawn to seeing the finished 3D printed tactile paintings on display in various museums, not only did I want to 'use' the tactile paintings myself but I also wanted to see how it was being used in the situated context of the museum. During the semester I was able to pay a visit to not only the display in the Kunsthistorisches Museum in Vienna but also an exhibition specifically designed for the visually impaired at the Museo del Prado located in Madrid[21]. As the field of research for the ethnography part of the thesis were museum exhibitions, access to the field was relatively easy. The Kunsthistorisches Museum is located centrally in Vienna with their public display of the 3D printed tactile painting located in one of the main portrait rooms. It was quite easy to participate and observe, once during Lange Nacht der Museen (Long night of the Museums) and also during my own personal visits to the museum. Using ethnography and participant observation, I aimed at being able to analyse and explain the practices of using the 3D printed tactile painting during time with the developer and separately in the context of the museum. Participant observation and ethnography were important to have as an additional method for the exploration of the case study for a number of reasons. Firstly, participant observation requires the use of our senses and it seemed fitting that such a method would be applied into research that focuses on this exact topic. I was able to use this method to describe not only what I saw but also what I felt when I touched different prototypes that the developer presented me but also during my time in the exhibitions using the tactile paintings. This allowed for a more in depth observation of the actual use of the exhibition and also allow myself to use the

[21] My research led me to the exhibition '*Hoy taco el Prado'* or '*Touching the Prado'* which was mentioned in the first interview with the developer.

technology of tactile paintings in a museum for its in scripted purpose. Though the ethnographies were short, I did observe very compelling data about material, colour and use of the technology in the situated context, which will be elaborated on in the Analysis chapter to come.

Also as an additional method, documents and videos were analysed. The videos chosen for analysis were clips provided by the different organizations to understand how they want to present themselves and the technology to the public. Three videos were analysed, two from the website page of Artecontacto: one news clip and one promotional video of an exhibition and one promotional video by the company that developed the tactile paintings in the Museo del Prado, Madrid. All of these videos were transcribed both visually and orally and coded manually.

3.2.3 Ethical Considerations

An important component when conducting research is reflecting on the ethical issues involved with the project. The first interview that was conducted was with the developer of the technology. The developer agreed to an interview as well as the use of a voice recorder. There were a number of different things that the developer wanted to be informed about, such as what the thesis was about, if he could read it later and if there were any direct quotes to ensure that they were not misquoted. Besides that, the interview was quite standard and occurred in a shared space where his office was located. As the developer had already published his work and had many press interviews, my interview and questions didn't seem to bother him. The only moment where the developer was reserved was during the end of the interview when discussing the work he was currently doing and at the negotiating he was doing at the time in relation to further work in the area I was interested in. He mentioned that when everything was finalized then he would be allowed to say, so this was disclosed through email at a later date.

As my focus on a part of society that feels excluded, there were a number of ethical considerations that emerged. Firstly, I would like to mention that it is not my intention to draw fundamental conclusions from the perspectives investigated in the interview with the two test subjects and that they do not speak for the visually impaired community as a whole but still are valuable perspectives that need to be addressed in this study. It would have been impossible to comprehensively investigate this case study without a view from the test subjects as there are many assumptions that even as I started communicating with these individuals that I found I took for granted. As I wrote my interview questions for these test subjects I started to realize how little I actually know or understand about living in our modern society with a visual impairment. Issues such as getting informed consent from the visually impaired interviewees and organizing where these interviews would take place had to be considered carefully. A different method of obtaining informed consent had to be used compared to standard signed consent form and location for interviews had to be made sure were locations that the interviewees already knew or can be found on a regular day. Secondly, anonymity and privacy were also highly valued considerations when investigating this case study. That is why I referred to the individuals I quote in this thesis as either the developer or test subject 1 and test subject 2.

3.3 Data Analysis Approach

3.3.1 Staying grounded in Data

As the research for this case study started quite broad, the method for data analysis was grounded theory in an attempt to follow the data into a natural focus. Grounded Theory can be understood as a guideline for collecting and analysing specifically qualitative data to construct theories that are rooted or grounded in the data themselves. Unlike abstract theory where analysis begins with a hypothesis, grounded theory works in reverse where first data is collected, then it is coded several times to concepts and categories that us as researchers can create a theory from (Charmaz, 2006). It was first introduced by Anselm Strauss and Barney Glaser in '*The Discovery of Grounded Theory: Strategies for Qualitative Research'* (1967) and developed during their time collaboratively studying the experience of dying in hospital patients, it was during this research that lead to the development of what is now known as Grounded Theory (Birks & Mills, 2011). It has since grown into a widely used method that has been appropriated by a number of other scholars (Bowers & Schatzman, 2009; Charmaz, 2006; Clarke, 2005).

The decision on using grounded theory was influenced by how it allowed myself as a researcher from developing preconceptions of the data before analysis. Through the use of grounded theory my aim was to stick close to the data as possible not relying on assumptions I may have projected on to this research. The in-depth step by step method that was provided by Kathy Charmaz in '*Constructing Grounded Theory: A Practical Guide Through Qualitative Analysis' (2006)* was followed.

After transcribing the field notes, I first conducted an initial coding, which involved remaining grounded and open to the data. It is the first set of codes that are done on the data and usually focuses on what the data is trying to suggest and whose point of view is this data trying to communicate. By sticking closely to the data, initial coding allows one to avoid making large conceptual leaps that are not necessarily supported by the data. The initial coding was done by flipping back and forth between line-by-line and incident-to-incident to insure that all of the data was read and also read in its narrative context. This allowed myself to identify implicit concerns within the field notes, identify gaps within data, break up the data into concepts and categories, compare the data from each interview and participant observation and also reflect on how I brought my individual context to the data (Charmaz, 2006). The initial coding was then followed by a focused coding which built on from the initial coding, where the coding becomes more selective and concise, in order to bring large parts of your data together. This was done by focusing on the reoccurring codes and the codes that seemed the most significant. It often occurred that after focused coding I would go back to initial coding, repeating this cycle for a number of weeks. With the end result being able to distinguish analytical and conceptual parts of the data. This was finally followed by an axial coding where the broken up data from the previous coding would be joined together in larger categories. Allowing more coherence, axial coding lead to more fully formed concepts that were later expanded on in memo-writing (Strauss, 1987; Strauss & Corbin, 1989, 1990).

The coding was done both using software such as Atlas.ti and QCA map[22] and on paper, as I struggled to find the perfect technique for coding. This lead to a stretched out period of time before I started being able to analyse my data, or I was already analysing my data but I didn't it know it yet. From these codes, memo writing was done in order to be able to stretch out a theory relevant to the data. Memo-writing provided a way to start writing large texts concerning the categories that were formed in coding, which later developed into drafts of this thesis

As I have shown in this chapter, this case study involves a number of different mediums which especially at the beginning were all valuable to the research project. Due to this grounded theory was the best approach in analysing the data collected as this method can be used across a variety of different mediums and documents and coupled with many different research methods.

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[22] Atlas.ti and QCA map offer support when it comes to dense coding with possibilities to turn codes into word counts, tables and diagrams which help in categorizing and constructing theories and frameworks

4. Analysis

In the following section of my thesis I will be presenting the main results of the analysis from the empirical material that was collected during the assembly of this case study in accordance to my main research question:

> *How do researchers at VRVis develop 3D printed tactile models in order for the visually impaired community to gain access to art?*

I will then follow this up with results related to the sub questions which I have provided previously in the chapters above. This analysis chapter will be divided into four sub chapters that correlate with the sub-questions I have mentioned before: The development of the 3D printed tactile painting, the imagined users of the developer, the various narratives of the users and test subjects including the context of disability and impairment and also my own narrative as an STS researcher. I hope that by acknowledging these different strands of narratives I can highlight the role of all these discourses and themes and how their interaction with each other came to produce the final 3D printed tactile painting product.

The first half focusing around the development of the technology is where the reader will come to understand in more depth how the technology was developed, the process of the developer and the technical difficulties were faced with the design practices. We will also see how the idea of the technology was developed and how it grew from an idea into a physical technology and the motives behind the different actors and groups that were involved in the development of the technology. It is in this section where the opening up of the case study starts and where we will specifically explore the concept of designing for another. The section will expand on the technical challenges that arose in the development process and explore the user imaginaries of the developer during these moments.

The second half focuses around the role of users in the development of the technology, specifically the test subjects who were the initial users of the technology and had a significance presence through the various phases of development. This section will begin describing the context of the user as visually impaired museum visitors and then will be followed by their involvement in the development of the technology. How the users engaged and participated in the development and what this looked liked will be focused on, followed by how the users perceive the technology itself and the differences between the two test subjects in how they viewed the technology.

4.1 Developer's perspective on Developing 3D printed tactile paintings

From the early stages of this research project and thesis I have always concentrated on the development of the 3D tactile painting. Whilst researching online about the technology I came to find an organization, Artecontacto, based in Vienna and Barcelona, who were responsible for collecting new ways and techniques for communicating visual art to the visually impaired. It was first my idea to focus on Artecontacto but as I became more involved in my research, I was drawn into a different direction. During my online contact with the founder of Artecontacto I was lead to the developer of the technology itself, the computer scientist who developed the technology from an idea he was approached with into an actually tangible product. It was from that point on where I focused on the developer and his team and the users they engaged with.

The whole context that this technology is situated in, is quite complex and large as I came to find during my research. There are a lot of different actors that are engaged with each other in different ways and it is my goal to at least paint an overview of what this context looks like while also focusing on the development of the technology. In the most basic sense, a technology can be seen to have two sides, how it is developed and how it is used. Using this idea of two different sides of technology, I aimed to focus my attention onto the earlier side of development and production. In order to understand the production and development of the technology, we need to understand how the 'need' for this technology was created.

4.1.1 Technical aspects of the development of 3D tactile printing

Since the beginning of this research project, one of the main goals was to get more insight into exactly how a technology such as 3D printed tactile models come to exist, from a need, to an idea, to an application until it is finally a tangible product. In order for this to happen, I spent much time with the developer of the technology, asking very specific details into how their process was. It is in this section that I will try my best to explain the technical aspects of the development and shed some light on how the project begun and the circumstances behind it. To begin my investigation into the development of the 3D tactile paintings, I conducted a semi-structured interview with one of the research designers behind the Tactile Paintings at VRVis. It was decided that this would be the best approach in order to understand the aims and assumptions behind the design project of the technology. Through initial contact through email an hour and a half interview was conducted at the location of the test subject's office at the VRVis Institute in Vienna. During the interview the the test subject showed me much of their work, different prototypes of their technology, videos of the computer software used and presentation slides to explain some of the more detailed parts of the design and development process. This section of my analysis will focus on what I learnt during my first interview with the developer, specifically engaging with how they developed the 3D printed tactile painting, how they got involved in development of the technology, what steps the developer took, what decisions they made and why and also their challenges.

During the first interview with the developer I was quite curious about the whole process and interested in how it technically came about. Though much information was released in his research papers he published about the 3D tactile paintings, much of it was better explained in person with the test subject as well as through video presentations that the developer had on hand. One of the interesting comments that the he made about interviews in general was how they had many interviews with interested people and almost always had to answer the same questions. '*Yeah, It's always the same questions'*-Developer (Interview 19th of March, 2015, Line 543)

The first interview of this research project also coincided with my first interview ever as an STS researcher. So no training in the world could have prepared me for such a nerve wracking experience, as I made my way to the interview location at the VRVis office, I continually read the prepared questions I had with me over and over again. As I arrived to the office I was taken to the developer in question to their office and was taken aback by the shared office space the developer worked in, I wasn't prepared to have other colleagues of his present in the room but as the interview started I was less aware of them (unless they took it upon themselves to interrupt the interview). There was no space for me to sit so I was on my feet walking back and forward a lot from where the developer's computer stood to where he showed me the prototypes he created. The interview was made up of a lot of pacing back and forth from these spots. Before conducting the interview, I read about the design process on their website and in their research papers and was always drawn to the developer's statements about how he worked closely with users throughout their development. This was a really interesting aspect of this case study and it was in this interview that I wanted to find out exactly what kind of relationship was present between the users and developers during the development phase.

It was from my time with the developer that I learnt much about how the project started and how the developer themselves got involved. Initially starting when the idea was brought to VRVis by the Kunsthistorisches Museum in collaboration with the Ministry of Education, Art and Culture, with KulturKontakt Austria acting as consultant and advisor, the KHM were eager to improve their accessibility aspects of their museum following the steps of many museums around the world. VRVIs, Austria's largest independent research institute in the field of visual computing, an already active partner with the federal government and the city of Vienna were approached with the job mostly because they are the best in their field. VRVis have a large scientific cooperation network that includes Harvard University, Stanford University and the Technical University of Vienna (TU)and have been involved in a number of projects surrounding visualization, rendering, computer vision and visual analysis. What made them highly suited for developing the 3D printed tactile paintings was their experience and expertise in reconstructing 3D object using images and laser scans, which were necessary for implanting the development of the technology. So through KHM, KulturKontakt Austria and the Ministry of Education, Art and Culture, the project had been granted some money and the developer was assigned to the project as he was free at the time. From the beginning the developer had great excitement for the project. "*I was assigned to it and I really loved to work on it because it has to do something with art and yeah it's fun it's a little different than all the rest that my colleagues do" (Developer, Interview 19th of March, 2015, Ln 43).*

The development process began by choosing three portraits found in the Kunsthistorisches museum's Renaissance collection for translating. Together with the KHM three portraits were agreed on, ***Madonna with the Christ Child and Saint John the Baptist*** (Madonna im Grünen) by Raphael, ***Madonna and Child*** by Albrecht Dürer and ***The Court Jester Gonella*** (Der ferraresische Hofnarr Gonella) by Jean Fouquet as these were thought to be the best and more well known paintings from their permanent renaissance collection. The museum wanted to be able to add a new way to experience these paintings and decided to improve an already existing tour specifically for the visually impaired. Before 3D printed tactile paintings, this tour only consisted of dialogue with the guide and audio descriptions for the comprehension of the painting including subject matter and composition.

The developer went on to describe that the Madonna im Grünen by Raphael (see Figure 1) was selected first to translate as initially it was thought it would be the easiest to translate because the structures and lines were more clear, however throughout the process he would find out that this was not the case. The portrait to be translated is scanned in order to produce a very high resolution copy of the portrait. A high resolution copy is needed for the translator to be able to see every inch of the painting clearly through the display screens and also to prevent unwanted pixels and artefacts later in the actual 3D printing image, which in the final stages is done pixel by pixel. This high resolution scan is then simplified into the most important structures of the painting, which is decided by the translator manually by digital tracing using a tablet connected to the computer. In order to be precise, this step usually takes up to one day to cover all the lines.

Already in the beginning stages of development, decisions by the translator/developer have to be made such as, what are the important structures of the painting. It is also possible that this is a step where the translator's preference could influence the translation a result of them identifying a structure to be more significant compared to if another person translated the painting. When asked about this, how it is decided what is important, the developer stated he approached this challenge by getting familiar with the painting and trying their best to understand what the original artist's intent was with each brushstroke. The developer found that this step allowed time to get familiar with the painting up close and this was helpful in identifying what the original artist was presenting as an important structure.

> *"We use the tablet here and trace it and it takes about one day to get all the lines but it's great, you get familiar with the painting, up close and you can, sometimes it's very difficult to decide what's the intention of the artists especially if it's a blurry picture or painting so yeah this is more or less the first step"* – Developer (Interview 19th of March, 2015, Ln 91)

Figure 1 –Original artwork (left) and Edge image with different line types and fill patterns to distinguish different

By the end of the process, what is left is a black and white image or an edge image that represents what is a dividing line and what is a continuous surface. This 'edge image' can be supplemented with different line types and fill patterns (see fig.1) and then printed on swell paper to produce a tactile diagram, however this is still basically a two dimensional diagram. In order to develop a 3D tactile relief picture, more steps are needed.

In order to achieve 3D information in the tactile paintings, information about depth needs to be included into the image. This is addressed in the next step where height/depth information is manually added to the images in order to create the sense of depth. For this step, the developer designed a program to help that process become more automative. The black and white image or edge image that the tracing process produced is imported into this program, where the areas bounded by black lines can be found. The program then allows the 'translator' to add arrows to these lines in order to assign certain height and depth values. Arrow drawn across a line (from one area to another establishes that the area is in front of the other area, whereas drawing a line from one area to another establishes a 'same height' relation). Height and depth values of areas are relative to the areas that surround them so by assigning these arrows or height and depth values to all areas, a network of height relations are formed. Once this was done and all the height and depth values computed, the program was able to produce a height map (see Figure 2, right).

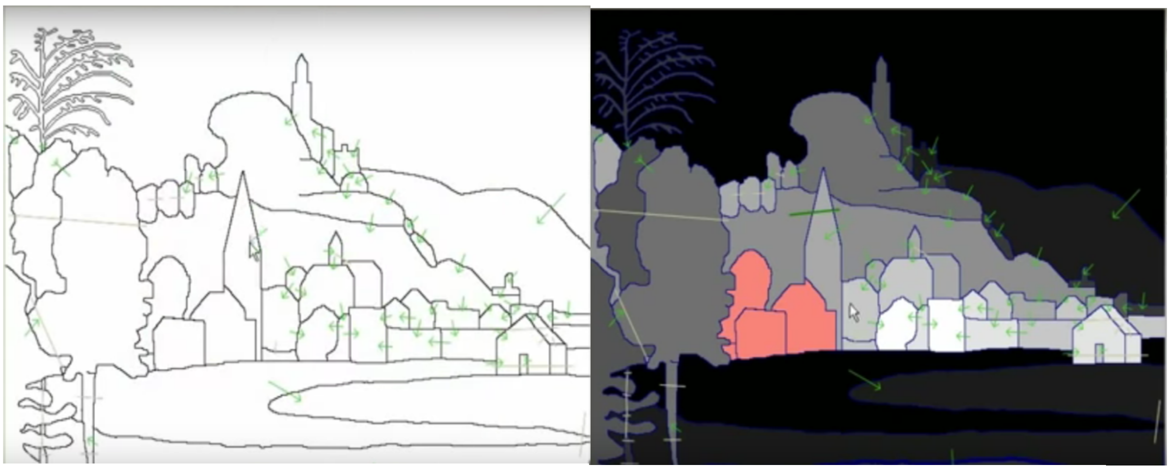

Figure 2- Height depth arrows (left) and height map with unassigned section highlighted in peach colour (right)

This height map is displayed using various shades and tones (see Figure 2) for different areas' dependent on that areas height value, any areas that have been missed when assigning a height value are highlighted with peach-red colour. White shows very high height values (essentially structures that are closer to the front of the painting) and black shows very low values (areas that are closer to the background), this colour scheme can help the ‘translator’ see how the overview of the height map looks with the arrows and lines (annotations) being interactively changed until the desired map has been achieved.

The next process for the translator was to see what depth variables were too thin or too discreet. As any depth variation between areas can be simulated through the computer programme, more consideration was needed in order to physically manufacture and fabricate the depth, such as the printing technique and also the material being used. Specifically, another obstacle that emerged during this process is what the developer noted as ‘bend areas’. These areas are continuous areas that gradually vary in height and cannot be a constant height. Such as an arm that stretches out around an object. In order to communicate that through the program and then to the printer, these bend areas need to be addressed. In other to do this, the developer added additional algorithms to the program in which the translator would be able to highlight these bend areas. The program would then subdivide the original bend area into areas that can have different heights and smoothly interpolate between these new height values, creating an even increase in height.

From here the height map was then put through the first stage of a two-part printing process, where it was horizontally sliced into consistent layers that were then glued on top of each other, ensuring that the height map and bend areas were fulfilled within this. These layers were shaped using laser cutting techniques and then assembled on top of one another. The result is a layered depth diagram. Usability tests were then conducted on these diagrams but what was found through discussion with test subjects was that this is still not enough detail, as not enough tactile information or sensation was communicated (See Figure. 3, left). The test subject communicated that the textures of the painting were important to them, as the layered depth diagram had many large areas such as grass, sky, skin, cloth, that were smooth with little textural information. With this information, the developer added a second printing stage in order to continue to build textured relief on top of these layered depth diagrams he had already created.

Figure 3- Layered depth diagram, a result after the first printing process (Left) and Textured Relief model, the final product of both printing processes (Right)

In producing detail or texture relief, an extra production technique was used to add finer details of surface textures such as material of clothing and clouds in the sky, that could not have been translated using the layered depth method mentioned above. The developer created an interactive 3D preview that allowed them to inspect and adjust the height map produced above in real-time. Textual information from the original painting itself was extracted from the high resolution scans made in the beginning and added to the height map from the layered depth diagram using a filter bank which can be configured by the developer. Unlike in the first process of layering the diagram, which is concerned with depth and heights of layers, this second process deals with texture specifically relating to fine detail. Visually, we see details through our ability to pick up specific spatial frequencies (referred to as spatial vision), which allows us to resolve and discriminate features over an area of space and is measured using spatial frequency[23] (Goldstein, 2013). The developer had to understand this in order to simulate it haptically, which meant understanding spatial frequencies. Variations in brightness is an important element of this

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[23] According to Goldstein's Sensation and Perception (2013, p. 421) , Spatial frequency refers to 1. "*As a grating stimulus, the frequency with which the grating repeats itself per degree of visual angle. (One cycle of a grating includes one light bar and one dark bar.)*" and 2." *For more natural stimuli, high spatial frequencies are associated with fine details, and low spatial frequencies are associated with grosser features."*

as it is the individual cone cells in the retina that detect different brightness levels in a particular spot and send this neurological information to the brain. These variations in brightness and their frequency determine spatial frequency of the image. By detecting variations in light the retina can distinguish gaps (details), however the resolution limit of a given retina determines how small of a gap the retina can distinguish, once these gaps are too small to detect, objects appear to be one large solid object (Goldstein, 2013). So this resolution limit determines what is visible to the human eye and what is not. In the end high spatial frequencies result in fine detail and sharp edges and low spatial frequencies result in stimuli that are large and course such as general shapes for orientation. The purpose of the filter that the developer programmed was to copy this exact process by rejecting all input from outside the configured range (visible spatial frequency) while giving as output all the input signal within the desired range. This output is displayed through the programme resulting in an interactive 3D preview. This filter bank also equipped with an image processing technique that smooths away textures while also retaining the sharp edges of the image, creating clean edges for the next step of printing. The interactive 3D preview has also programmed many different parameter settings that can be adjusted and viewed in real time, which adjust the configuration of the filter bank. These parameters were designed to overcome difficulties that arose when unwanted patterns appeared such as steep spikes and peaks, which were the result of frequency outputs that were too high. The problem with this steep peaks and spikes when fabricated would be the possible danger or harm when touched and also their disruptiveness. The steep spikes and peaks that arose ended up masking the structures beneath, destroying the work that was done in the previous stage of producing the height map. The developer found that these occurred when spatial frequencies in areas were too high or too low and so filter bank parameters were adjusted for the purpose of preventing this.

> *"So I have parameters where I can interactively control it and try to mix different frequencies until I am satisfied with what I see"* – Developer (Interview 19th of March, 2015,Ln 326)

The frequencies came from the developer's configuration of the filters to mimic the frequencies that the human eye would register, allowing input that the 'eye' could see in the filter range and rejecting frequencies such as ultra violet light that the human eye cannot see. As the human eye is insensitive to high spatial frequencies and low spatial frequencies, we are unable to 'see' these and so the developer did not want these frequencies to be part of the translation. The developer used this range to adjust the filter parameters and so adjust the frequencies allowed in and used as output. So in order to ensure that the height of the painting and the brightness of the painting (information that was extracted from the high resolution scan) were separate, he looked at how the eyes work on a frequency level. In order to translate visually to haptically, the developer emulates the eyes with touch and it was through this idea that a filter scheme was developed to do this. This took a couple of times to get right as parts of the painting such as the hair in the first prototypes were too spiky and harmful to touch.

> *"So the idea is, I looked at what our eye makes, does and I don't know if you will understand this but more or less it says high spatial frequencies we are very insensitive to high spatial frequencies and for low spatial frequencies so we are more or less abandon these frequencies with our eyes. If we want to mimic eyes with touch, we should more or less do something like that. So I tried different filters and came up with a kind of filter scheme that makes sense."* – Developer (Interview 19th of March, 2015, Ln 320)

Additional information added to the textured relief were facial features, which the developer modelled using software packages that extract the face from scans of the original painting, these were then imported and added to the height map as a special 'correctional layer' which was blended with the rest of the layered depth diagram.

So now that these details and textures have been simulated on the computer, the next job is to fabricate them. In order to manufacture these finer details (textured relief) that have been added to the layered depth diagrams, a second part of the printing process was done using CNC (Computer Numerical Control) Milling machine. The CNC milling technique was used as the milling allowed to produce heights that were not restricted to the fixed thickness of the sliced layers, which was a concern if they were to use the printing process from step one of the printing. The milling was implemented on to the layered depth diagrams that were produced from the first printing step. These were already assembled, so the CNC milling was done building on top of them, since they already communicated the overall structure of the painting.

In order for the milling to be executed, these additional details from the simulation created above are converted into control codes for the CNC production, these codes are communicated through a type of software called Computer Aided Manufacturing software or CAM software which is responsible for the 3D modelling digitally. For this project however, regular CAM software were unable to handle the large amount of data given from the height maps created before and even CAM software that was dedicated for height maps were limited to a resolution of 8-bit[24]. A high resolution is needed to produce finer detail as the CNC machine mills to the exact pixel and a higher resolution will produce a more intricate detail that a limited 8-bit resolution would not have been able to produce. In order to overcome these limitations that came with the CAM software already available, the developer implemented their own CAM module, writing their own programme that directly outputs codes for CNC milling machines.

> "*So I wrote my own programme to generate the milling parts for the tool, which is quite easy but nobody has ever done it."* - Developer (Interview 19th of March, 2015, Ln 396)

The actual milling itself was a two step process, starting from a large block of material, a large milling tool is used to get rid of material, particularly doing the larger or rougher parts and then a smaller, finer tool is used to go into very narrow passages as small as two millimetres. This tool goes over the whole painting, getting codes from the CAM module and roughly takes eight to twelve hours depending on how much detail and height variation there is within the diagram.

> *"Basically, a grayscale dilution is performed on the input height map, with a height map of the milling tool as kernel. That yields the required tool offset, at every pixel in order to carve only that deep to let the highest peaks of the desired shape be unaffected. Caused by the tool diameter, fine low-relief details will be rounded, but our filtering method ensures that the important features are still preserved." (Reichinger et al., 2011, p. 10)*

Ureol was used for the milling, which is a foam of plastic with very good features for milling. Ureol is usually used for producing items such as mock buildings as it is similar to wood but has stronger properties. However, the downside to using Ureol is how

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[24] The problem with 8-bit height is that the resolution is too low and artefacts are found in the product, so a high resolution is needed. The developer stated that he always used at least a 16-bit resolution to avoid this problem, more pixels, less artefacts.

expensive the material is, especially if there are many 3D printed tactile models that need to be made.

Once this is done, the final product has been made, however as milling each one separately would be too expensive, for larger quantities a negative cast can be made from the final product and from this mould several copies can be produced. Copies were made with silicone, which are poured into the mould but this was then discarded as it was difficult for the material to harden evenly leading to loss of some detail in the copying process. Deciding on material was a decision that involved both the museum and the developers. A number of different things were considered with the developer thinking about what materials were ideal for production and the museum thinking about what materials were ideal for its extended use. The final material that was decided upon for the copies were discussed between the museum, the developer and the expert at the model shop who made the copies. The expert at the model shop made many different copies with different mixtures and a polyurethane mixture was chosen in a neutral grey. The colour of the material was decided upon by the representatives of the museum, who had discussed which colour would fit the room that these 3D tactile paintings would be displayed in. The final chosen mixture ended up being chosen for its robustness, how pleasant it felt to touch and also how it could be easily up kept in the museum, dirt repellent, dish washable and easily be disinfected.

4.1.2 Technical challenges for the developer

During my time with the developer, a number of interesting moments arose where we discussed the challenges that the developer had to overcome in order to develop these 3D tactile paintings. In order to better structure this analysis, I will distinguish between two main types of challenges that the developer faced, first the challenges that arise when attempting the difficult task of translating a two-dimensional image to a three-dimensional object. What makes something three dimensional? What visual cues can be communicated haptically? Can colour and transparency be translated haptically? How much of the translation process is influenced by translator's bias?
Secondly, I will highlight the challenges that are identified by the user. What is enough textural detail? How large do I need to make this image for the hands and fingers to be able to register it? This section focuses on the technical challenges for the developer and it is these challenges that I will go into depth below.

One of the main underlying themes or discourses that I found during my time with the developer was ‘sense’. Traditionally speaking we recognise in humans we have five senses: sight, hearing, taste, smell and touch and when comparing them we notably understand that each sense is significant in its own way, part of a system that underlies human function (Bynum & Porter, 1993). However, there is much debate surrounding what constitutes as a sense and what abilities or functions should be labelled a sense. Stimuli that the human body can detect and measure such as pain, vibration, temperature and balance could be argued as a sense but do not fall into the traditional five senses (Classen et al., 2014). During the interview it was interesting to see how the developer dealt with sense, in particular sight and touch. Throughout the interview these two different senses are referred to separately, with the understanding that very different information is obtained through each sense. However, with this in mind a common assumption arose, that one sense (in this case sight) could be totally substituted by another (touch). By attempting to translate different visual cues, the developer has come to think about sense in a totally new way. By the act of translating the differences between sight and touch are highlighted even more than they were before the development of this translation process.

> *“The medium is essentially two dimensional, layered depth diagrams. The human visual sense has the unique ability to defer the third dimension from various visual cues in the paintings. In order to add this information to the tactile paintings, we developed layered depth diagrams composed from several laser cuts” – Video presentation of Tactile Paintings*
> (Interview 19th of March 2015, Ln 168)

These visual cues that are mentioned can be specifically seen when the developer is dealing with the concept of transparency. Transparency by definition is the physical property of light passing through a material. This concept was tricky for the developer as being able to ‘see’ light passing through a material relies on the ability to register light in the first place. It can be described through words and sound but can it be translated haptically? Is transparency an important element to translate? Who gets to decide? This is one of the challenges that faced the developer when producing the height map for a woman’s transparent veil in a painting. The developer had to decide on one discreet height because when the eyes see a transparent object they actually see two heights simultaneously; this however is not possible to translate into touch. So in order to overcome this the developer had to decide, not just for himself as the translator but also for the original artist. It wasn’t just transparent objects that became difficult to translate but also certain information about depth such as how objects look at difference distances that were hard to convert into touch. The overlying theme became the difference between the eye and touch. The idea that the eye is detailed with a large range of visual cues compared to touch that needs to be exact as touch is more intimate but also more limited, for example you can't feel that an object is far away.

> *"Our eyes are very, very tolerant. We are used to seeing stuff but when it comes to touch, touch is something physical that has to be exact" –* Developer (Interview 19th of March 2015, Ln 123)

Following the concept of substituting one sight for another, this concept of '*sense hierarchy' (Foucault, 1970; Kambaskovic & Wolfe, 2014)* where sight is elevated and privileged over the other senses becomes prevalent when mentioning that the developer explains how the process is 'mimicking the eye'. The developer uses sight as a reference to point out how art was originally intended to be experienced and how the medium automatically excludes the visually impaired. In the modern western society, sight has become the most privileged sense. However, the idea that sight is preferred and touch is the substitute can still be seen in the development of the the technology.

> *"Our methods mimic aspects of the visual sense, make sure that the haptic output is quite faithful to the original paintings, and do not require special manual abilities like sculpting skills." - (Reichinger et al., 2011, p. 1)*

This can be seen in another moment worth mentioning during my time with the developer where we discussed certain details of the paintings and who these details were for. We discussed the significance of facial details in portraits which got me thinking about who exactly are the users and who is the developer developing for. We talked about the process of creating facial features and how they are added to the height map of the layered depth diagram.

> *"There is still something missing here in the face, umm, so if we just give it to a blind person they don't want, don't care much about face details, they say it's too difficult but since it is in an art gallery, it should be also pleasant for seeing people"*- Developer (Interview 19th of March, 2015, Ln 361).

It seems so obvious to the developer that the tactile translation needs to be made pleasing for the seeing without reflecting on the primary motivation for the translation being for the visually impaired. What is interesting here is the shifting of who the technology is being designed for, the main goal from the beginning is to have a product that translates what is seen visually from a 2D artwork to being communicated through haptic touch in a 3D tactile translation of the artwork. From what the developer knows from their time with the test subjects and personal experience with the visually impaired, he knows that facial features are hard to haptically translate. However, even though this is the case, the developer recognises that the visually impaired are not the only users the developer is developing for but in fact that these 3D tactile paintings will also been seen visually even though their main goal is to communicate haptically. Knowing this, the developer goes out of their way to spend time using software packages to model faces in order to add that information to the height map and blend the facial information to the rest of the diagram.

One of the biggest and most interesting challenges of translating from sight to touch for the developer was communicating colour and the colours used in the paintings. This challenge can be seen as both a technical challenge involved with the translation and also a challenge that users identify with. Colour is an important element in visual art and is a significant tool for an artist's expressions, communicating a range of different meanings. Scientifically, colour is considered visual as it is our eyes that allow us to 'see' or pick up colour and compared to black and white which are understood as structural tones, colour visions requires a very specific photoreceptor in the retina, cones. What is interesting about colour vision is that the perception of colour is quite subjective depending on how an individual processes the stimuli that is produced when incoming light reacts with their cone cells. In a way, different individuals see the same illuminated object or light source in different ways. It was very important for the developer to understand how exactly the eye works.

> *"So the basic idea is we only use the black and white channel, cause also our eye also uses the black and white for structure and the colour is actually a lower resolution, so just additional information, which is nice but doesn't give us any structural information, so we use only grey scales"* – Developer (Interview 19th of March, 2015, Ln 255)

When answering the question if he would consider translating colour, the developer gave a mixed answer and started describing what he knew about what visually impaired visitors want when they want to know a colour. By trying to consider how to communicate colour through the technology, the developer started to question what the purpose of the 3D printed tactile paintings would be. He came to the conclusion that the most important purpose for the 3D printed tactile paintings was to be able to communicate haptically textural information to be used by the Kunsthistorisches museum either accompanied by a guide, audio guide or braille text description. The 3D printed tactile painting's purpose isn't to replace already existing techniques and technology already in place in museums but to accompany them and enhance them. A detailed description, either verbally or with braille, of the piece would initiate a mental depiction, but falls short when describing positions and relations of different parts of the painting. This is where the 3D printed tactile painting would be beneficial as it is much quicker by touch to comprehend where one object is in relation to another than by verbal or written explanation. The 3D printed tactile painting would also allow for the individual to focus on areas of the painting independent of the audio guide or guides description and in a way allows for more of an exploration into a painting, similar to what visual abled visitors would do when looking at a painting. If something grabs their attention more, the more they can focus on it.

> *"You have more possibility to explore more on your own and its good to verify your mental image if you depicted correctly but this is also saying first there is textural description and then this is the tactile painting. You can't just give a tactile painting to a blind person… For most people you have to give the introduction and then you should guide him or her while touching and give feedback, more of an interaction."* – Developer (Interview 19th of March, 2015, Ln 279)

As the process of translation can be seen as an interpretation of the original painting, the subjectivity of the translator was another theme that occurred many times. There were many decisions that developer and subsequently the translator will face in translating the original image into a 3D relief pictures. From the beginning of the development process, the developer asks what do they want to include in the tactile versions, what types of material, textures and curvatures they deem to be significant. A particular example of these types of decisions can be found in the process of tracing the painting's significant shapes and lines, the translator may come across lines that are not exact or hard to see. The translator needs to trace a line for the software to recognise shapes within the painting and for this reason the translator needs to make the decision of where that line goes.

> *"Exactly and it's very subjective ... So it's actually very hard to see the dividing line here, it's all blurred out, the cracks and the brushstrokes but not sure and yeah but its background of course but for me it was important so yeah you have to more or less decide, where do you want to put the line"*- Developer (Interview 19th of March, 2015, Ln 111)

The translator's subjectivity also comes into play as mentioned above when the paintings contain transparent objects as the translator has to decide on one set height to be printed and milled. The translator has to decide what is the best possible height to communicate the shape and figures haptically. This can be difficult as understanding what the original artist intended is often hard to do, as the translator has their own subjective reading of the original artist and this often influences the translator's decision.

> *'When there is transparent stuff, yeah for this process I have to decide for one discreet height and if there is something transparent then you actually see two heights simultaneously but you couldn't touch it so you have to decide for one or invent something to display both'* – Developer (Interview 19th of March, 2015, Ln 163)

It is interesting to see how the developer engages with the idea of translating for an original artist. The developer spends much of their time getting to know the painting but in the end the translation in a sense can be seen as an expression of the translators subjective reading of the painting. The developer doesn't see himself as too much of an artist but a mere tool in the process of getting this work to the visually impaired. However, in all these decisions and solutions he comes up with in the processes, the developer's decisions affect the outcome of the final product. It makes one think if the final product is a 'translation' or could it be considered a piece of art created by the 'translator'. In order to answer that question, we would need to answer what art exactly is and this is not what the thesis is about. However, it is a good question to ask when thinking about the purpose of the translator and what is regarded as important.

> *"Of course with the tactile paintings we are dependent on what the tactile painting artist makes out of it"*- Developer (Interview 19th of March, 2015, Ln 278)

4.1.3 The developer's imagined user

An important part of any design process is the user's influence on the developers and the technology being developed. However, historically, the relationship between designers and the users has always been somewhat problematic. From design attitudes that assume designers know better to design practices that limit the ways in which users can be conceived, understanding user's needs and adapting appropriate design methods has been difficult. It has only been in recent years that the idea of user centred design and participation design has been implemented by some designers. Nonetheless how developers see and imagine users of the technology is an important aspect of design and an area that is very interesting in understanding designer's decisions and processes. In this section I will not only identify the developer's experience with their users but also where these meaningful interactions between the developer and users come and influence the development of the technology. Using the developer's narrative and recounts of the design process, I hope to identify key user imaginaries that the developer depended on during this period.

During the interview with the developer, not only did I come to understand more about how the technology was developed and insights into how the developer perceived the technology, I was able to get a clearer picture of how users were involved in the development of the technology. Before this first interview I was afraid that the role of the user in development would not be as significant as I hoped at the beginning of this investigation but as I continued discussing the issue with the developer, I realised how important they were for the design process and for the developer's conception of the technology. The most obvious 'users' that were involved in the process were the visually impaired test subjects that the developer consulted. These test subjects were called upon to use for the first time and comment on a variety of prototypes that the developer produced. They were responsible for giving the developer insight into the needs and wants of a visually impaired museum visitor and also insights into life without sight. Once comments, suggestions and opinions were made about a prototype, the developer took these comments and went back to develop the technology further with these suggestions in mind.

As these tactile models were specifically designed for the visually impaired, the test subjects' role in the development was extremely important as the developer relied heavily on this feedback for he himself and the museum which funded the technology were not personally visually impaired. The developer was unable to extract from their own personal experience of being visually impaired so understanding the perspective of the user had to come second hand either by the test subjects or through the developer's research. Design concepts such as I-methodology (Oudshoorn et al., 2004) cannot be adapted by the developer of 3D printed tactile models which opens them to other possible ways of conceptualizing the use of the technology and it is how these concepts emerge that this section is interested in. From the beginning of development, the developer's imagined users has been a distant group that the developer has had trouble accessing. The developer acknowledged that he could not personally subscribe or put himself into the perspective of the user. This can be seen throughout the interview with their use of language and heavy emphasis on 'we', 'us' and 'I' compared to 'they' and 'them'. The developer often emphasised that myself the researcher and the developer were part of the community that were visually able, *'we can see this'* and the visually impaired community were another, *'they tell me, they don't like this' etc*. This is what makes this design case study unique as the developer is unable to consider themselves a representative of the user, this is a challenge that is faced from the initial stages of development onwards. This leads to a unique relationship between developer and user, where the developer relies heavily on user feedback and usability tests. He is neither designing for everybody nor designing for himself, he is designing for a very specific part of the community.

Often there were different moments in the interview with the developer where he refers to his time with the test subjects and recites what the test subjects had said to him. Mostly these times were when he was justifying certain decisions he made during the development of the technology, showing how significant these moments were to the developer. These moments were the ones that seemed to stick with the developer and it was this knowledge that the developer would draw back on when conceptualizing not only how the technology is to be made but also why.

> *"We did a round, it was a little too late because we all took longer and yeah it was a little more expensive that we had funding money but we did one round with these guys, Test subject A and B and they gave me very good feedback for instance that this was not enough for them *holding out first prototype with not a lot of detail*. They simply wanted not only the surrounding, dividing lines but they also want to feel how the painting*

> *feels in these areas and that's then why we developed the second and third prototypes."* – Developer (Interview 19th of March, 2015, Ln 134)

Here the developer mentions feedback about the first prototype that had only gone through one stage of printing, the dividing lines that are mentioned refer to the lines that outlines the different structures in the painting, lines that are traced during the beginning phases of translating. The developer refers to this feedback as motivation for developing the product further, test subjects were not entirely satisfied and the developer had no qualms about rectifying this to the best of their ability. It is through this feedback that the developer goes back to develop an additional printing process in order to meet the requirements of the test subjects. These usability tests were very important, allowing the developer to navigate through the design process influencing the direction of development and what the developer would focus on next.

> *"They found it nice to have the outlines (border of paintings). They could easily orient themselves on the image but they also wanted to know how the painting feels in these very flat areas."* – Developer (Interview 19th of March, 2015, Ln 236)

These usability tests and feedback were also used by the developer as motivation as the developer strived for positive remarks from the test subjects. What is interesting though, is that the developer also had to consider another user other than the test subjects, the museum. KHM also emerged for the developer as a user during the design of the technology and in many decisions the developer can be seen to be going back and forth between the users to ensure that all users were satisfied. The museum was an important user to consider in design as it was the museum that approached the developer, funded the project and is also where the technology will be housed and used. The museum uses the 3D printed tactile paintings in their art education programmes and the original artworks also belong to the museum, so it is important for the museum to be involved with decisions that involved in how it will be displayed and maintained. It is interesting to see what decisions the museum is involved with and what decisions the museums leave to the developer and test subjects for example their involvement with choosing colour and material of the tactile paintings.

One of the most important topics that the developer was able to learn through their time with the users was *how* exactly the technology would be used. The users explain how they would go about 'reading' a painting and the whole process involved with it including how long they would use the models. Through this the developer found out that the amount of paintings need to be translated in a museum would be around three or four pieces or paintings as 'reading' a painting by hand is more time consuming and requires a lot of concentration. More than a few paintings for each tour was described by the test subjects as too much and overwhelming. This influence from the users lead to the decision of the developer and the museum to choose only a few of the most famous and sought-after paintings to translate. Translating more artworks would only make sense for regular visitors that come more than once, however due to the lack of accessibility for the visually impaired, this is rarely the case and is one of the issues that the 3D printed tactile models hopes to improve.

> *"So what blind museums visitors tell me is seeing three or four pieces is enough because it takes a lot of time for them and a lot of concentration, so more than a few is too much for them. So it makes sense to create the most famous or the most sort after images in this kind of way OR you could translate all of them but if you have regular visitors that they come more than once, only then would it make sense"* – Developer (Interview 19th of March, 2015, Ln 427).

Other times, the developer spoke as a representative or spokesman for test subjects, almost in the way of assisting someone. The imagined user is thought of as part of a community that needs assistance, not just in accessing art but accessing other parts of society that they are regularly excluded from. However, through researching and spending time with test subjects, the developer was able to accumulate anecdotes and experiences that were helpful for the developer in conceptualising the use of the technology and what the technology was going to be. Through the development process the developer came to understand that not only can he assist the users but that users also can assist them in doing so. Some concepts such as colour were subjects that were better decomposed by discussing it with the test subjects. The developer refers to these moments specifically because they are moments that the developer himself found interesting and through this he began to acknowledge how much of a learning experience this was for himself personally.

> "*So what I found out is that when a blind person wants to know colour she or he doesn't want to just find out it's green or it's red, they want to hear or feel whatever that this is a dark blue velvet and find a nice texture of garment… or that it is a fresh green meadow or this kind of brown."*- Developer (Interview 19th of March, 2015, Ln 262)

Another observation that was seen was how often the developer referred to test subjects when describing challenging times in the design process. During these difficult times, the developer turned to the user in order to rationalize some design processes that could have restricted the user's needs and requirements. For example, the developer discussed a specific remark given to him by one of the test subjects regarding translating folds of material usually clothing that appear in paintings. The developer established that this was one of the most difficult obstacles to overcome when talking about fabric and how the users relate to different materials. In actuality, when you touch a fold of material it is not rigid and changes form, practically disappearing. However, when represented in material that is not cloth such as wood or plastic, folds do not have the same characteristics and become rigid and fixed. This then to the user is not a relatable representation and could be miscommunicated as something else entirely. It was difficult for the developer to come up with a touchable detail that could be relatable for the user. Whether this came from the test subjects or from other research, the idea that blind people do not like tactile representation of *folds* is presented as a logical fact that is unavoidable in their design. Here, the user's needs are considered as an obstacle, something that needs to be taken into consideration but unhelpful in the current design process. The developer refers to the test subject's comments in order to justify why this is a problem.

> *"This was very difficult to model, the folds. But blind people actually don't really like folds at all because they can't relate to them. When they touch a statue they say, 'what is this stuff', 'I can't feel it' because when you touch a fold in actually material, it disappears"- Developer (19th of March, Ln 491)*

Another important experience that the developer used in conceptualizing the user was understanding the use in the context of the special guided tours in the museum. During most usability tests, the developer grew fond of the behaviour of one test subject who did not like having the painting explained before feeling the model but first wanted to see how much she could understand by just exploring it first through touch. "*Don't tell me anything, I want to touch it on my own".* As the use of the tactile model was intended to be accompanied by a description and guide, the test subject's behaviour resisted this intention. Through this behaviour the developer was able to see the technology being used without the accompaniment of description, essentially as a decontextualized artefact. This lead to better feedback of the model from the test subject and for the developer was enjoyable to observe as he could see how well the model was understood by itself.

Through this the developer discovered that what the users want is agency, which was significant for the developer to imagine his user. Before the tactile models, visually impaired visitors were unable to access the painting by themselves but needed an introduction, description and guide. The aim of the technology was to allow the user to explore the painting on their own and help verify the mental image in their head created from the description, for example for things that are harder to describe audibly such as positions and relations of structure and objects to each other. This context allowed the developer to understand that the user wants to be more independent, experiencing the art for themselves and not relying on the perspective of the person describing the painting.

The project was given to him by the Kunsthistorisches Museum, so imagined use of technology is in museums with the imagined user being the blind and visually impaired visitor. However, the developer imagines this user to be one monolithic group and uses the limited number of test subjects to be a representation of the whole community. Though the developer might consider that each individual varies, design practices and the development process are unable to address this as this would be impractical and juxtaposes one of the goals of the technology which is to increase automation, which can not be done by producing customized pieces.

> *"The aim of the work is to bring the cultural heritage of two dimensional art closer to being accessible by blind and visually impaired people. We present a computer-assisted workflow for the creation of tactile representations of paintings suitable to be used as a learning tool in the context of guided tours in museums or galleries." - Developer (Reichinger et al., 2011, p. 1)*

The developer is aware that not all of the test subjects' feedback and comments can be addressed in the design of the technology. It is helpful for the developer to see the user as one collective imagined user than many individual users with unique needs and requirement. If designing the technology involved design for many different wants and needs, the technology would not have been completed or turned into a customization process which was the exact opposite of what the goal of developing the technology was, automation. Drawing from the test subjects and their own research, the designer was able to create a user to design for, which was important in the absence of design techniques such as I-methodology, where designers can design for themselves. It is unclear whether or not the design through these design processes was reflecting on the heterogeneity of the users or in fact building an imagined user from these experiences. It could be a bit of both.

The context of the museum where the technology was to be used was very important for the developer and lead to the museum becoming somewhat of a user. The developer had to take into account how the technology was going to be exhibited and what other materials would accompany them. This influenced some design decisions such as material the developer was unable to produce the tactile paintings in soft materials which some users would have liked, but had to consider how many people would touch the tactile paintings and think about maintenance.

The developer mentioned that before being assigned to this project he knew very little about accessibility issues, especially for the visually impaired in museums. "*Has my view on accessibility changed? Yeah of course it has changed, now I know about it" (Developer, 19th of March, 2015, Ln 577).* It was through the assignment of developing this technology that the developer was exposed to these sort of needs and communities. The developer has since initiated more projects in the direction of accessibility for the visually impaired in museums. So not only have these users influenced the development of the technology but also the developer's interest and future projects.

The most interesting aspect of the developer's imagined user is how much it is tied with the developer's perception of the technology itself. Through the design process we have seen that the developer's decisions are not just influenced by the feedback from users but also influenced by the context in which the developer imagines the use of the technology to occur, in this case the museum. The fact that the technology was to be used in the museum affected aspects of the technology such as what material it was made from, the colour of the material and other aesthetical aspects that are not important to the central user. The fabrication of the facial details in the tactile models was just one of the design decisions that was influenced by the developer's imagined use of the technology, the developer knew that the models would be displayed also for seeing people and this was one of the reasons why the developer went through the trouble of modelling the facial details of the tactile models even though the visually impaired user had no use for these details.

The perceived use of the technology including the context in which it will be found influences how the developer may see the user and how the developer goes about manufacturing the technology. User imaginary and perception of technology influence each other and it's the interaction between the two that produces the final product.

4.2 Users' perspective and role in design

In the development of a technology that is designed for a very specific user, understanding how the technology is used and how users perceive the technology is just as important as understanding how the technology was developed in the first place. In this section of the analysis I will focus on the experience of the users involved in developing 3D printed tactile paintings. The role of users was widely discussed in all of the interviews conducted during this project with both the developer and the two test subjects, both who are involved with the Bundes-Blindenerziehungsinstitut (BBI) in Vienna and who were both present during the development of the technology. This section focuses on my time with them and their experiences they had with the developer and the design process. Discussing similar questions that I had with the developer about significance of the technology and how they view assistive technologies, my time with both these test subjects was extremely eye opening, not just in what was discussed during these interviews but also how these interviews played out.

When going through my material from my time with the developer what I found was that I have no idea what the life of a visually impaired person looks like, how they use certain technologies and how this technology might fit into their lives. So much of my time with the test subject involved me not only asking questions about their role in the development of the technology but also question such as what are the most important technologies in their life, how they conceptualize colour and helped me confront the assumptions I made about what is seeing, visual art, visual impairment and assistive technologies.

Through a forwarded email by the developer, I started my contact with both test subjects online. Even the beginning process of organising interview times through email had made me start to think about how technology fits into the lives of the visually impaired community. I started to think about how exactly the test subjects had read my email, if it was speech output or some other type of display. I started to worry about if writing in English was a problem or not for the speech output and if calling on the phone would be better. It was through this initial contact that I truly found out how little I knew about being visually impaired. I started to research more online, reading interviews with other visually impaired people about just their average day to day life, I started to notice structures in the city such as floor markers in U-bahn stations and braille on pedestrian lights. Never before have I really thought about thinking for these needs in design until starting this research project and it was this type of thinking that highlighted what I take for granted or what gets 'black-boxed' in my own life.

4.2.1 Understanding user's context: Life with a visual impairment and everyday technologies

The context of disability and impairment is one of the most prevalent aspects of this case study and one of the reasons that make this case study unique. Literature surrounding designing technologies for disabled people has been an interesting focal area within STS studies, with a number of different STS themes being made present in these literature studies, such as the enactment of disability in design and how developers conceptualize disability. This is why I believe it is important to dedicate a section to understanding how the technology of 3D printed tactile models fits into the lives of the visually impaired community. In order to do this, we need to discuss and explore how life with a visual impairment looks like and what already existing technologies are interacted with. Below I will elaborate on my time with the test subjects where they helped me understand how their lives with technology were. Both test subjects took the time to talk about their visually impairments, the specific stories and what they find significant in their lives, such as their challenges and if they ever feel limited or excluded. This will be followed by a sub-section where I will take from these interviews and investigate how this influence the design of the 3D printed tactile models.

As the research project centres heavily on the community of the visually impaired, it was extremely important to understand how everyday life with a visual impairment may be experienced and not just in the context of art galleries and museums. The first interview with the test subjects was with the I.T. teacher and network administrator at BBI (Test Subject A), who I met up with after calling the contact number they sent in an email. We decided to meet in front of the institute and I remember I was quite nervous that I let them pass me, without saying anything as to not startle them, so followed them into the building silently until one of their colleagues had told them that I was only a few steps behind them. We greeted, shaking hands where they held their hand out in front of them quite still waiting for me to grab and shake. After this polite courtesy, test subject A led me to a quiet conference room in the institute where we conducted the rest of the interview. This was the first time I have ever been led by a blind person and it was interesting to see how well they knew the building, using both the floor markers provided and also what seemed like memory. There was a moment where they struggled for a few seconds finding the door handle, which stood out for me as an interesting moment, as I battled with an impulse to grab the door myself. Once inside we sat down and I found myself narrating what I was doing such as getting my notepad and recorder out and also letting them know exactly which seat I had chosen, I didn't know what was helpful and what the procedure was. Of course not having a set procedure helped me identify what it was that I was actually doing and how I was doing it and the reaction of my interviewee to my actions and vice versa.

The interview began with asking about their role in the institute where I found out what they had studied and their interest in information technology (IT). This made for an easy transition into the discussion of technology and technical aids for the blind and partially sighted. They started with describing the most important technical aids they use in their day to day lives. The Braille display which is a refreshable device that connects to the computer is used to display text outputs by raising pins through holes in the surface of the device, the device displays information that is run from the computers screen reading software (Schmidt, Lisy, Prince, & Shaw, 2002). This is one of the most important technical aids as this connects the individual to the computer and the internet which is the most influential and important tools in most peoples lives. The second important technology that they described was their mobile phone. Using the speech output feature on an ordinary smart phone, they showed me exactly how it would be used by running a finger across the screen of the smart phone. By doing this the phone outputs speech that allows the user to tell them what app it is. They described that nowadays these are the two most important devices as well as their ordinary watch that they use to tell the time by lifting the glass face of the watch and feeling where the hands are placed.

What I quickly learnt throughout the interview is that Braille[25] is a very important part of being able to communicate as a blind person and soon learnt that they had been blind from birth so started to learn Braille at a very young age. I am intrigued at the difficulty of learning another language as I am one of those English speakers who is only fluent in one language and ask further about learning Braille at an older age for people who become blind later in life. Test subject A later explained that Orientation classes like the ones at the BBI are specifically tailored for this purpose.

> *"There are many many steps or phases between normal seeing and total blindness and this often combined with having no German as their first language and maybe not so good school education before coming to the*

[25] Braille is not a universal language but a universal writing system such as Latin script or Cyrillic. This system consists of raised dots that can be read by the finger, with a full cell having six raised dots arranged in two parallel lines. In Braille, there are a possible of 64 different combinations and the 'A' of latin is the same as the 'A' in Cryllic.

institute for the blind so in this orientation class, there is a lot to do for them, not only learn Braille, to handle a computer, to learn German speaking ... " - Test Subject A (24th of July, 2015, Ln47)

Though there are some individuals that don't know Braille, they must rely on speech output. An available feature on most modern technologies such as computers, mobile phones, navigations systems etc., speech output is also a very important technological feature for modern life with a visual impairment. They explained that the speech output allows them to quickly go through emails and messages as the speech output is faster than the finger, with an added benefit of having hands free to type when listening to the speech output. The most interesting part about speech output is the speed, which is much faster than the average spoken voice. It is very common to be trained to listen to fast speech output with a majority of visually impaired people being able to understand four to five times faster than the average person. As they showed and explained how the speech output on their mobile phones works, there was no way for me to actually comprehend the rapid speech that came out of the phone. I could only imagine what checking their emails must sound like.

Another significant part of life without sight is navigation and orientation. The ability to get from one place to another, point A to B is a skill that is needed to be able to participate in most of society. Test Subject A explained that technologies that assisted with orientation are relied upon heavily if they are alone. They obviously could be guided around most places, and especially new and unknown areas but for independent travel, these technologies are a necessity.

"Until now I can not really know when the next tram is coming, well I know it but if there are two trams, two different types of trams in the same station or two different lines. I don't know if this is the line or the other line." – Test Subject A (24th of July, 2015, Ln 313)

They went on to explain that further development into these technologies such as GPS are important and that they need to be improved on as they still are not accurate to a certain number of steps which is necessary when you can not see where you are.

"It's not every time I need assistance of course I can ask but um well if I have to find, lets say a village, I was born in a village and if I was to be there and I had no help, eight o'clock in the evening there is nobody on the

> *street so its quiet, so how can I find the Heuriger for example. That would be hard…that's why I said navigation systems are so important and would become a great help if they develop that further and further"* – Test Subject A (24th of July, 2015, Ln 329)

Just like the test subject A, test subject B discussed a lot about technology in their life. Through the interview they strongly expressed how important and significant the role of different technologies had on their life. Test Subject B unlike test subject A, had been some partial sight until the age of twenty where they went completely blind. They explained this was quite stressful for their parents who did not know what to do but eventually sent her to a special school in Vienna away from her family. They started to learn Braille at around seven even though at that time they could read big letters. A big part of their experience with their visual impairment is anxiety and it was this anxiety that pushed them to rely on certain technologies such as the white cane for mobility and orientation. If it wasn't for technology such as floor indicators and special traffic lights they would have had to rely on a guide. They later explained that there were many different technologies that they need in order to get to their work, to do their work and generally participate in society. A few that they listed were the computer, the Braille display, speech output, smart phone and their white cane. They followed by mentioning that if they were afraid of losing these technologies.

> *"You know there are many thieves in Vienna and so I'm not afraid that they take my money, I'm afraid they take my technology… that would be the worse for me"* – Test Subject B (23rd of September, 2015, Ln 178)

Both test subjects in their interviews talked about their frustrations when it comes to their everyday life and how they experience exclusion and inaccessibility.

> *"Of course for me it is also frustrating if I personally get difficulties made only by blindness, but I am not frustrated with my personal life. I think I am old enough, I find the ways to, I have a good self consciousness, so its easy."* – Test Subject A (24th of July, 2015, Ln 366)

> *"Mostly, the small things are frustrating, you go to the tram and you cannot find the spot or when you go into a restaurant you can't see where the next free place. You can choose, I cannot choose. These are the most frustrating things in life, things everybody can do and I can not. Not the*

> *big things, I have a job, I have a family, I can live, I have my holidays, I can go to different countries but the small things are a little bit frustrating and you can not do anything against it."* - Test Subject B (23rd of September, 2015, Ln 265)

What I came to learn through both the interviews was that like most people in society, every individual is different when it comes to how they see their lives, how they experience it and how they participate in society. Though the two individuals that I talked with were both visually impaired, their experiences with their impairment were different and unique to their own situation. In the following section I will elaborate less on the user's context and more on their actual role they had in developing the 3D printed tactile paintings.

4.2.2 Users' experience participating in the development of 3D printed tactile models

As I have highlighted earlier, the participation of the test subjects was a crucial element to the development of the 3D printed tactile models. Though user centred designs are becoming more prevalent in the modern days of innovation, this case study is quite unique because the concept of 'the designer knows best' goes out the window. The developer acknowledges how little they know about how to use of the technology should be which opens the door for significant participation from the test subjects and users. This section will specifically concentrate on how the users (the test subjects) participated in the development, their experience, what the test subjects considered when giving feedback and also how they got involved.

The involvement of both test subjects began when the KHM approached BBI to create the catalogues for the museum in Braille that would accompany the 3D printed tactile models in their new guided tours for the visually impaired. One of the test subjects was the director of the Braille centre which would be responsible for such a project. It was during this project that it was suggested for them to try out the models and see how they were like. The second test subject was then approached by the first, as they were involved with information technology (IT), enjoyed going to museums and art galleries and were familiar with similar technologies. Both test subjects met with the developer a number of times during the course of the development, around four to five times in over a year.

The test subjects' involvement began when the developer came to them and asked them what they needed to be able to recognise an object. This of course was very difficult for the test subjects to communicate entirely but something that had to be overcome. They both understood that the transferring of these images was something that cannot be perfected as the finger is very different from the eye.

> *"You cannot describe what you need but umm we informed him, we showed him some material we have from other museums and so on. So he had to check what he needs to do and what he must make and what he can leave. So that's the problem and then he came with the first prototype, the second one, the third one, the fourth one, to show us and we told him what we could not recognise. So step by step we came to something that we could use. It cannot be perfect because you cannot make an object like a painting, you cannot have it so the same information for the fingers is as it is for the eye. But I think we go to the best of what we could do"* – Test subject B (23rd of September, 2015, Ln 79)

The developer made a number of different prototypes and after each prototype was made, usability tests were arranged and the test subjects interacted with the prototypes while giving feedback to the developer. These meetings were usually done with both test subjects together and during these encounters many different issues were discussed. Exactly how the tactile models were used was an essential part of the user's participation in the development of the tactile models and imperative for the developers understanding of the technology.

> *"First I would like to have an overview. How much is on it? Maybe it is only a big plate and a small object on it. So I want to know how complicated it is and second the shape, so here you can find, oh a head, another one and here you have the cane and the most, how can I say, its like you look at it and there is a point of interest that you see first and then step by step to find what else is here and I tried to find out what it should be and maybe it would be nice to have someone that I can ask if I don't know"* – Test Subject B (23rd of September, 2015, Ln 220)

By understanding how the 3D printed tactile models are used by the visually impaired to comprehend the image, a few different issues could be found in the translation process. The main issue that was brought up by both test subjects during these meetings was how the fingers register detail. Understanding how and what the finger receptors can register was key in developing a 3D printed tactile paintings that could communicate an image haptically. The ability for visually impaired persons can be trained and heightened through everyday use of reading braille and tactile maps but the developer still needed to know how much detail is possible to detect. Both test subjects had to explain to the developer that too much detail and information can 'overload' the fingers and this can result in the fingers not recognising the different structures in the tactile model.

> *"He said he learnt a lot, spent much time alone to look only at the painting and to recognise what's there and what he could make in material and what he can no do. So if it is too much for the fingers you cannot understand anything. So you must have the most important things, and I think this was the most difficult part of the project"* – Test Subject B (23rd of September, 2015, Ln 91)

Test subject A specifically spoke of a certain model which they remembered quite fondly. They used this model as an example of why it was important for the developer to understand finger recognition. Referring to a tactile model of a hunting knife with an engraved handle (see Figure 4.), they discussed with the developer in-depth about the sizes of the different shapes in that engraving, if they were large enough to recognise and if it was too detailed for the finger to distinguish one shape from another. This discussion with the developer resulted in an additional model that sat along side of the knife model of a dog that was present in the engraving. By isolating this, the developer had hoped for the users to be able to distinguish the animal separately from the engraving in order to give more context to the engraving. This is quite similar to a diagram that displays a zoomed in part of a painting in order for the viewer to see all the details of the painting. If it was not for the input of the test subjects this detail in using tactile models might not have been understood as well and steps taken to address this would be not present.

“*So what can a finger recognise and what can it not recognise. I think this was the most important thing. Especially, lets talk about the knife. There are on the handle, the dog and so (carving). How big must this shape be that I can recognise that it is a dog?”* – Test Subject A (24th of July, 2015, Ln 144)

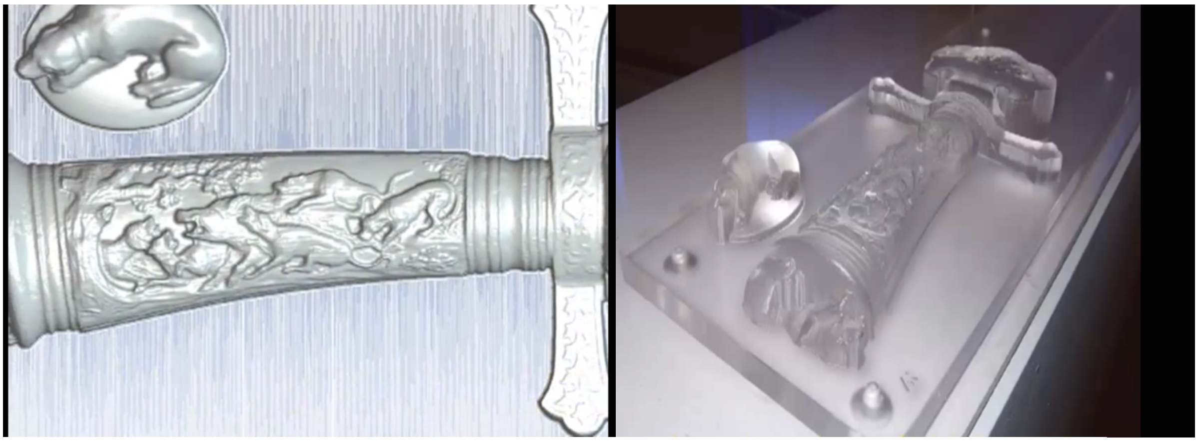

Figure 4- Scan of Engraved Knife Handle (left) and Milled Acrylic model of engraved Knife (right)

The process of feedback giving was one that involved a lot of cooperation and teamwork from both the developer and the test subjects. Both groups acknowledged that they don’t have the same terminology as each other and come from different backgrounds. This didn’t stop them from learning from one another in order to complete the project.

“We had to learn from each other, to understand what we are meaning because we do not talk about the same thing but it was not really complicated. I think we had very good communication. We were a group and we asked each other what we are meaning and I think it was not very difficult” – Test Subject B (23rd of September, 2015, Ln 98)

Though the experiences of the test subjects were similar, their opinions on different elements of translation differed, giving the developer and themselves plenty to talk about during their meetings. Colour was an important issue to discuss, whether there is a lot of colour or no colour, it is very relevant to visual art and the visual experience. The two test subjects had very different experiences when it came to colour, Test Subject A had been completely blind since birth and for him personally, colour wasn’t important but the meaning that the colour conveyed was significant. However, they understood that it would be important for other visitors in general.

> *"My really personal perspective is, because I am blind from birth, that colour is not important for me. Test subject B got blind later, she will say of course colour is important. A colour* ***could*** *be important for me if this is not only the colour eyes can see but if we can, really develop a transfer from the optical colour to some haptic symbol or code to tell for example, it is dark or light. It is not possible to say 'oh well put this kind of surface to express this colour' because it has this or that meaning. Because colour of course have meanings and not every red colour has the same meaning as there are different types of red."* – Test Subject A (24th of July, 2015, Ln 154)

The opinions of Test Subject B were slightly different due to their history and having partial sight in their childhood before becoming completely blind. As they have experienced and used colour before they believe colour is important for distinguishing different paintings and objects and its important for practical things such as orientation and maps. In contrast to test subject A's opinion of colour as meaningful, colour for test subject B sees colours importance as a characteristic of a painting, that could be used to distinguish it from another.

> "*If someone tells me its blue I know that if other people talk about the blue painting I can recognise it, 'oh they are talking about this' or to differ one from the other. So I like to know what the main colour is in this painting but I don't know if it is really important. I would like to know but its not important to understand what is on the painting but it is useful*" - Test Subject B (23rd of September, 2015, Ln 227)

Test Subject B goes on to elaborate on why colour indications can be useful in society. They emphasise that colour is important when it is being used practically, using an example of the underground map of Vienna were indications of different colours are used with the tactile model both visually and in Braille.

> *"Not in paintings but I think it would be useful for the underground, you have the blue underground, red underground and so on. Colours would be interesting for such things, practical things but I am not sure if it is necessary for paintings you have the words, the descriptions for the paintings. There are experts you can see about the colours and they*

> *quarrel. You have a green or blue and some people might say it's greener and then others day it's bluer and you have sunlight and then you have a lamp. I don't know if colours are really so important, I think it is for practical things, for orientation to know. To distinguish."* – Test Subject B (23rd of September, 2015, Ln 235)

During the interviews I asked both test subjects what was the most important detail that needed to be translated for them. This question got varied answers as both test subjects wanted different things from the tactile models. For test subject A it was '*the position of the persons in relation to each other'*, which relies on the use of the tactile model as audio and braille descriptions can be difficult when explaining where objects are from in relation to one another in a painting. As for test subject B, what was important happened to be '*the expression of the paintings'* which could not be communicated through the tactile models but in descriptions of the paintings. For this reason, these descriptions accompany the tactile models in order to contextualise the tactile model.

> *"I must know what the others say, I cannot see the expression of the face, is the person look sad? Or are there tears? Is she laughing? I don't know and this is very difficult to understand, so I need the words to get hint of the expression of the paintings"* – Test Subject B (23rd of September, 2015, Ln 334)

These differences in between the two test subjects quite convincingly show how varied and different the individuals that can be found in the visually impaired community. This was just one of the many things that the test subjects taught the developer during their participation through usability tests. What I personally found fascinating was how each individual involved viewed the development process. Their recounts of the process were quite diverse with the developer focusing on all the technical processes and the test subjects with their subjective experiences. However, all involved described the process as a learning one that revealed more and more until finally the development process ended with the completion of the final tactile painting.

> *"It was very interesting for me to see how it grows from the first thing, it was something to touch but not to understand and it got better. It is like light in a room, when it is dark and you can see with every step a little bit more. It was very interesting"* – Test subject B (23rd of September, 2015, Ln 102)

4.2.3 Users' perception of the technology

The user's experience and influence on the technology was analysed in the previous sections, however what is fascinating is the user's perception of the technology and how this influenced how they interact with the technology and ultimately the development of the technology itself. A number of different topics came up during the interviews with the test subjects which reveals a great deal of how they felt about the technology, the future impact of the tactile paintings, what part they have to play in development and if this technology can really benefit the community of the visually impaired. What I found very interesting were the vast differences between the two test subjects, which I found had very different and sometime opposing views of the technology.

When it came to understanding their overall perception of the technology, it was interesting to see test subject A and B's different answers. Test subject A, who is quite involved in museums and is very interested in technology, viewed the developer's tactile paintings as a very encouraging technology that does not have to be exclusive to its use in museums and art galleries. They feel that it is a bridge to new and exciting ways of accessing all types of things in the world.

> *"It is important because it is a new way of access to these things… of course the first thing is for it to be used in a museum but maybe there are other areas, for example, we have children here and maybe they, or maybe not, they like cars and airplanes and whatever. So if we had a good system to make these things accessible, because you can not touch an airplane on every side, its too big. And if you have a good way to make them tactile, touchable or understandable, this is good."* – Test Subject A (24th of July, 2015, Ln 88)

The most important aspect of this project for test subject A was the technique itself and that energy and man power is directed into 3D printing in order for it to develop further. They believe that there are still many possibilities that this technology of 3D printing can be achieved and it is great that it is being used for visual art but if it can be used in visual art why not other areas.

> *"I think the most important thing is to find the technique (3D printing) and then well of course you have to look it this is suitable for blind persons and so I think the technique is the most important thing and that a person does*

it and that they begin to develop these thing" – Test Subject A (24th of July, 2015, Ln 81)

This view of the technology is completely different and almost challenged by the views of test subject B. Test subject B who is the director of the Braille centre at the BBI, has admitted that she doesn't often go to museums and that it is only when she is travelling to different countries that she may go to a museum. Test Subject B believes that the work of the developer is interesting but not necessarily important compared to other work in the world. She is quite cynical about the interest and funding behind the technology as she believes that other work would make more money. Test Subject B perceives the technology 3D printed tactile models for the transferring 2D visual art as more of a privilege than something essential to the needs of society including the visually impaired community.

> *"You can try but you must have the money to do and the persons who know like the developer, there are not too many people who are interested in such work because you cannot make money with it. It should be but there are at the moment so many people who do not have enough to eat, so I don't want to ask for paintings to touch, it's a question of priority. Yes I would like it, yet it would be nice to have. It is nice to have but it is not a necessity, I must confess."* – Test Subject B (23rd of September, 2015, Ln 198)

Though test subject B has this view, she still believes it is important to be able to get an idea of what the world looks like. *"It is important to get a picture from the world, from things you cannot see, you cannot touch them" – Test Subject B (23rd of September, 2015, Ln 143).* The problem for test subject B is that she believes that the technology of tactile paintings is still a niche market and not something many people know about and can invest in or participate in developing further.

> *"I'm afraid not too many people know about it, it is always the problem to communicate it to the people who are interested in it. You see not everybody is interested in such material and I think for sighted people the same, some like to go to cinemas and others do not. And therefore its not too well known I think."* – Test Subject B (23rd of September, 2015, Ln 138)

She also highlights that visually impaired museum visitors are a very specific group of people and that not all visually impaired individuals are interested in going to museums and art galleries. Though this could also be an effect of the inaccessibility that is experienced by visually impaired visitors and now that now that 3D printed tactile paintings exists, maybe this might change. *"Everything is interesting if you cannot see it and then you have the possibility to touch it"* – Test subject B (23rd of September, 2015, Ln 254).

Regarding how the tactile paintings are used and if the technology has a chance for changing how the existing visually impaired visitor experience the museum, they both believe that it is something progressive but elaborate on different parts of the technology when discussing this. Test subject A sees that the technology is a vast improvement from Bas relief models that are currently used in most museums now and that the difficulty with Bas relief is that the image that is transferred is not relatable to the object that it may represent in reality. They refer to an example of using a knife and knowing how that feels in their everyday life and that a good tactile model feels similar to this object which they already know. That is one of the issues that comes with transferring visual images to haptic models as visual images are purely visual representations of things and objects and their transfer can sometimes result in the image not being relatable to the actual object found in reality.

> *"This is more complicated then three dimensional model objects, because if it is a tangible graphic on paper of course you can say it is three dimensional but it is not really three dimensional. The raised dots or the lines of areas are another thing to understand for a blind person than to having a three dimensional object in your hand that is relatable for example a knife. Well this is similar to a knife I use everyday and even if it's a knife from the 19th century I can tell it is a knife, but in a graphic if you see this photograph of a knife and raise it, it is not easy to transfer it in the brain from raised lines to the actual three dimensional object"* – Test Subject A (24th of July, 2015, Ln 107)

Test subject B understands that the use of 3D printed tactile models would be accompanied by descriptions either Braille or audio and that these are still an important part of the experiencing art and museums. One cannot entirely replace the other but 3D printed tactile models do improve the understanding of the descriptions of the paintings.

"If you make it from words you really do not know or if you want to follow a line and it is not a straight line but a specific shape, you cannot describe it, you have to touch it. ***You need both****, words for detail, for describing, for helping to understand what you have touched and you need the other (tactile model) to confirm the picture that you have made in your head."* – Test Subject B – (23rd of September, 2015, Ln 154)

Later in the interviews both test subject elaborate on the limitations they have come across not only in museums and art galleries but in other parts of their life. Test subject A described the biggest limitation that they generally encounter was the very small and very big objects in the world. Referring to the macro and micro world test subject described that if an object or thing is too small or too big there is no way to imagine what it would look like and these are areas of their world that they cannot have access to except second hand.

"The limitations of the bigness and the smallness of objects. The macro world and the micro. I can not really imagine the surface of the moon. I can not really imagine how these animals with one cell look like, the microbes and so on." – Test Subject A (24th of July, 2015, Ln 175)

They go on to express that the technology of 3D printing may be able to change this but that for the most part right now, this is inaccessible to them. When it comes to specific limitations within in museums and art galleries, both experience the same exclusion. They both understand that visiting a museum is different for seeing visitors compared to visually impaired visitors, with their limitation being not able to choose or decide for themselves what they would explore.

"Well and so, the limitations in museums are I think are of course it is expensive to have accessibility but I think its not necessary that every object is accessible because many sighted persons they visit a museum in fifteen minutes because they walk by pictures and they will 'oh that look fine' or whatever. This is impossible for a blind person, either you inspect an object in detail or you leave it. And of course by the group of objects which are made tangible, there is an influence of the curator of the exhibition. So a sighted person can maybe she goes in ten minutes through the museum but she finds one picture. Nobody looks at it but for her it's the best and this is of course not possible for blind persons." –Test Subject A (24th of July, 2015, Ln 178)

> *"Yes, you are able to have an overview. Yes, if you can see, you must concentrate on less objects, not too much but what you do want to see you do so intensively. Its is like you go through the museum and you decide what objects you want to see, you go to the objects,* ***but*** *I need someone to bring the objects to me, and therefore I cannot really decide what I want to see in there"* – Test Subject B (23rd of September, 2015, Ln 289)

Test Subject A goes on to elaborate that what the technology does allow is the independence from the interpretation of someone else. Before tactile models were used in museums and art galleries, visually impaired visitors relied on descriptions created by others. Understanding that art is very subjective, the descriptions are made to be as accessible as possible but are still the opinion and description of how someone else has experienced the artwork with their own visual sense. This of course is not entirely terrible to have, yet it is limiting for the visually impaired visitors that can not take a look for themselves and decide if they agree with this description. However, 3D printed tactile models allow these visitors to be able to create their own opinion through their personal experience interacting with the models. Obviously, these models can be seen as products of another person's translation of the painting but both test subjects feel that this still creates some sort of independence.

> *"It is an interpretation, in the texture and in its parts, it is an interpretation and it should be an interpretation. The main thing is that I have access to this art."* – Test Subject A (24th of July, 2015, Ln 209)

> *"For us it is more understanding, I want to know what it is and if it is beautiful for me, it depends on the description of the guide"* – Test Subject B (23rd of September, 2015, Ln 319*)*

5. Conclusion

The aim of this thesis was the investigate the case study surrounding the development of 3D printed tactile paintings used to translate visual art for the blind and visually impaired. By conducting in-depth interviews with the developer of the technology and the test subjects involved in the process the following research questions were answered below:

- *How do researchers at VRVis develop 3D printed tactile models in order for the visually impaired community to gain access to art?*
- *What user imaginaries are built into these tactile models?*
- *How do the users involved in the process perceive and effect the resulting technology?*
- *How does the context of dis/ability and impairment influence these processes of innovation?*
- *How does the developer come to terms with designing for a user that they are unable to embody?*

Below I will outline the various outcomes of this thesis, both in terms of the development process of 3D printed tactile paintings, my own personal experiences engaging with this case study and a number of interesting aspects of my research that emerged.

5.1 Experience as a researcher

Through out this case study, I have come to learn a lot about design practices, designing for another, museums, accessibility and visual impairment. In this section I want to expand on my own personal experience in understanding this technology and the context it is situated in. I began this case study with a personal interest in museums and have always found the role of museums in society fascinating, especially in relation to public knowledge. It was just incredibly good timing that lead me to museum studies journals that were very interested in 3D printing for conservation in museums. The excitement surrounding 3D printing was based on the ability of 3D printing to reproduce accurate replicas of artefacts and open a new door in terms of materiality and communication of knowledge in museums. It wasn't long until I stumbled upon the project at VRVis that was locally based and accessible for myself as a researcher in addition to dealing with materiality in museums.

I didn't realise how much I would encounter in trying to unpack this extremely interesting case study. Especially when it came to encountering visually impaired persons and technologies, I didn't realise how little I knew and how much I assumed about living in society without sight. Now that I have gone through this case study, I have become more aware of how a technology is designed and now attempt to deconstruct most technology I encounter in order to understand how the designer would see me as a user.

There were a number of moments during this case study that stuck with me that I want to briefly write about. One of those moments was when I realised that the experience of museums that I am most drawn to could not be experienced by the visually impaired visitor. My favourite part of going to museums is to explore and scan through the maze like paths of a museum, scanning and taking everything in and when I see something interesting stopping and taking time looking and learning about that specific piece, almost like a treasure hunt. This type of experience is not possible for a visually impaired visitor, who have special guides that take them to direct locations to view set pieces that have been prepared and translated for the access. They are unable or it is undesired by at least some to get lost in a museum and many prefer to have a guide to help them around a museum. Though as myself who has the set abilities that I have, should take into account that I may also be missing out certain experiences that visually impaired visitors have and that I cannot experience.

One of my biggest revelations has been that visually impaired persons are not just one group in society but are comprised of many different individuals. For most of my life I have conceptualised the visually impaired as a part of society that do not have the ability to see and that has been the only way I have conceptualised them. During this case study I have come to see that the range of different individuals in the visually impaired community, differ just like individuals differ in any other part of society. Now at this point in my research it seems obvious that this would be the case but it really has been interesting to see how surprised I reacted to learning more about the life of the test subjects and how they experience their visual impairment. Just from interviewing two people from this community I came to realise how many different opinions and perspectives can exist within a certain community. There are many different ways that visual impairment can be experienced, from how their impairment came about, to their degree of impairment to what decisions they make when it comes to their impairment and the disability they experience in society.

There were other trivial things that I found interesting such as how fast the speech output that they use was. I was amazed at how incomprehensible the audio of their speech output was for me and also the different technologies that already exist for the visually impaired. It was during this case study that I saw how public areas in cities were built to allow access for the visually impaired. It will no longer be possible to go to a museum without checking out how they create accessibility for the visually impaired and no longer possible to see 2D art and imagine how it could be translated into a 3D object. There are still so many different areas of this case study that can be focused on and many more questions that can be answered but opening up and exploring the case study has been enlightening for myself personally as a researcher.

5.2 Interactions between Developer and Users

One of the main concerns of this thesis was how the developer interacted with the users in the design process and how the developer constructed the user and user imaginaries. The developer used both first hand and second hand experiences in forming his user imaginaries such as his own personal research using literature and the internet as well as spending time with the test subjects. Time with the test subjects particularly changed the developer's initial user imaginaries as the developer came to further understand the experiences of the test subjects in relation to the technology and the context it is located. The developer recognised how little knowledge he did have on the subject from the beginning, increasing his motivation to seek out literature, organizations involved in museums access and the users themselves. Though, the developer only had two test subjects, the stories of their experiences were used by the developer to build a general visually impaired user imaginary. For example, by taking needs and suggestions from both the test subjects individually and presenting it to me during the interviews as a solitary monolithic user group for example when speaking for the community as a whole, *'Blind people don't really like folds' – (19th of March, Ln 491).* Obviously, this opinion was not formed by surveying the entire visually impaired community but rather from the developer's own experience with that community. This was a form of negotiating his initial user imaginaries by combining all his experiences and research into one singular ideal user imaginary, which may have made the process of design easier.

It was in later stages of the design, that another user emerged for the developer in addition to the test subjects: the museum. Through the developer's own research and time with the test subjects, the developer created his own 'blind' user imaginary, which was a mosaic of all these experiences. As the developer was not able to position himself as a user, he had to construct his own user imaginary of a visually impaired museum visitor. In order to this, the developer also had to imagine the actual use of the technology in the context of the museum. This imagined use was seen when deciding on materials to use and also including facial features of the paintings that the test subject mentioned were not important to them, but would be important to seeing visitors at the museum. How the developer imagined the technology, how it would be used in the museum and even where it would be displayed were all considerations that the developer had to address when constructing an imagined use and user. This could tie in with the Hyysalo's practice bound imaginary (2006) as the developer imagined the use of the 3D printing tactile models in the practices of the museum. However, I would not argue that it was only the practices of the museum and the practices of the developer that influenced the developer's user imaginary but also the interactions with the users themselves.

One of the more interesting parts of the thesis emerged through the interactions between the developer and the test subjects during the development of the 3D printed tactile paintings. Within this development process, a number of considerations had to be made by the developer as a number of obstacles surfaced through translating a 2D image to a haptic model. The first and most obvious obstacle to the developer and the reason why this case study is unique is the position that the developer found themselves situated in and their self-awareness about their situation. As the developer is not visually impaired and has not experienced a visit to a museum as a visually impaired visitor, the developer had to rely heavily on the test subject's feedback. Through this design process looked similar to user-centred design (UCD) mentioned by Massanari (2010), which focuses on the users' practices often by producing prototypes and constantly refining the design through usability tests. The feedback dialogue and how open the developer was to learning from the users looked a lot more as if the test subjects and developer were designing together which can be comparable to participatory design (Massanari, 2010). Even though the test subjects were not acquainted with the technical design processes, the developer was self-aware from very early on in the process about how much design knowledge the test subjects could provide, for example when discussing what resolution the finger is able to detect or when the developer was trying to understand how to conceptualize colour haptically.

The developer was also aware of the subjectivity of certain translation decisions that had to be made during development, such as how the facial features would appear and what lines were traced and what lines were not. As these were influenced by personal preference and aesthetics, it can be argued that the development process was influenced from the developer's sociocultural assumptions and not necessarily just reliant on technical processes. "*It should be also pleasant for seeing people*" – (Developer –19th of March, 2015, Ln 361). It was also interesting to see the developer switch from designing for the user and designing within the restrictions of the technology. The developer justified as many decisions as possible through a few different means. One way was by logically deriving to that conclusion through scientific or technical knowledge as with the example of the developer attempting to mimic the eye with the filter software or by his experience with the test subjects. Another through using the user's needs and preferences as a justification for example when mentioning that blind people could not relate to the folds of material that the tactile models produced.

For the developer the technology not only was a way for a group of people to access art, but a source of income and a responsibility. The developer felt that this social issue in museums is one that can be expanded on, even focusing future work on the same area. Through out the development process the developer acted as a provider or heroic figure that assisted the visually impaired users in gaining the accessibility they deserved. This can be seen as the common trope that exists in reference to user-centred design where the user is often seen as the victim of inaccessibility with the designer as the hero who provides access. (Massanari, 2010; Spinuzzi, 2003).

It was interesting to see the differences between how the developer perceived the technology and the users, and also the differences between the users. The process of the development involved two very different roles for both the developer and the user. The developer had a very technical process, whereas the test subjects had very brief and subjective experiences with the technology. The developer held the test subject's feedback very highly, using the feedback and wishes as goals to achieve, in comparison with the test subjects view of their own feedback, they didn't hold their opinions as highly as the developer. It can be argued that how the developer came to see the user was not only influenced by the technical process of the translation which Hyysalo (2006) would argue is the case but also by the dialogue or feedback of the user. A combination of this shows that through the unique situation of the developer being self-aware of his lack of knowledge, comes a new arrangement of how the developer has come to understand the user and the use of the technology of 3D printed tactile models that has not been observed in the literature above.

5.3 Translation: The process and the problems

One of the more thought-provoking tensions that arose during the research of this case study surrounded the technical process of translation, translating visual to haptic and all the challenges and obstacles that emerged through this. The difficulties that occurred during this translation usually stemmed from moments where touch and tactile sense could not substitute visual information such as colour and transparency. These moments provided a unique insight into how the developer conceptualized these sensory obstacles and also how he conceptualized his own role in the translation process as not only a translator but an interpreter. This dual role found the developer not only negotiating how to translate these 2D images to 3D haptic models but also trying to gauge what the original artist's intent was and therefore what needs to be translated. *"You get familiar with the painting, up close and you can, sometimes it's very difficult to decide what's the intention of the artists" – (Developer-Interview 19th of March, 2015, Ln 91).* This puts the developer in the middle of a number of different interactions, between artist and the visually impaired user as well as between the seeing world and the blind community.

This position as an interpreter, that the developer found himself, carried weight into the decisions he made in the development process. As Burri and Dumit mention, the production of representations are the result of a number of different decisions, that are not only technical but also influenced by cultural aesthetics. This results in representations being far from neutral but instead a product of 'culturally shaped negotiations'(Burri & Dumit, 2007). This can be seen in the case of 3D printed tactile paintings, where the subjectivity of the developer effects certain decisions in the design. There were times where the conversion of visual to haptic became difficult and it was during these times that the developer made a number of subjective decisions that influenced the final product. "*Exactly and it's very subjective"- (Developer - Interview 19th of March, 2015, Ln 111).*

5.3.1 How far can this translation go?

Even though there now exists a process to translate 2D paintings and artwork to 3D printed tactile models, the question still remains about how far this translation can go. During the development process, challenges arose that highlighted that touch can not substitute sight entirely, though this was the developer's goal. Visual cues such as transparency and colour elements that are unique to sight have no equivalent in touch. So far, this has only been addressed through mediated processes such as describing colour through language. These moments in the interviews were referred to as challenges and access to sight through touch has only been partially bridged. This limit to the translation can be seen as not only a result of the absence of technical solutions but also a product of our visually dominant society. Similar to Supper's argument of the legitimization of sonification (2012), there is still an attitude towards haptic representations as inferior to the original visual representation as a result of the still remaining hegemony of sight.

In comparison, the developer and test subjects understood that the 3D printed tactile paintings could not fully replace the services that were provided by museums before its development, such as audio guides and descriptions of the paintings. One of the test subjects expressed that some things cannot be touched such as the expression of a face. They emphasized that though this can be a goal for the developer to fully replace descriptions of paintings with tactile models, you need both, words for detail, describing and comprehending in order to understand what it is that has been touched and the tactile model to confirm the picture you have created in your head from those details. As information such as how one object spatially relates to another object is something that is difficult to describe through words.

Both the developer and the users experience raises the question, can there ever be a process that allows for a one to one translation from visual to haptic? How does this relate to a goal for a democracy of senses, can different senses ever be considered as equivalent or as legitimate as sight?

5.4 Answering Disability with Access

5.4.1 How visual impairment influenced the design of 3D printed tactile paintings

Through the interviews with the test subjects, a number of different technologies were mentioned that are essential to both their lives. Technologies such as Cash Test, a plastic device used to identify the value of notes and coins and the application of RDF tags used on clothes to coordinate their outfits. We can see that in most cases when there is an obstacle or a challenge, innovative technologies emerge in response to them. Visual impairment is just one of many disabilities that have created a need for innovative design.

> *"Either you curse the situation or you try to make it better" – Test Subject A (24th of July, 2015, Ln 373)*

Focusing on the design for the 3D printed tactile models, the interaction between developer and user had obvious effects on how the final product of the technology was created, whether this was the intent of the design or not. Users or test subjects in this case are not just categories for the developer to use but are individuals who interacted with the design and are influencing the final product. During these interactions, knowledge transfers occurred between the user and the developer, users came to know more about the technical challenges and financial possibilities and the developer was introduced to the user's context, this context being, visiting museums with a visual impairment. The design of the tactile paintings would not have been the same if the developer did not have access to the user's experience. Without this, elements of the design such as making sure structures could be registered by fingers, the amount of detail needed and structure of the tactile models in general would have turned out very different.

The user's role in the development and their first hand experience of their impairment in this context has lead to the design of a technology that is not solely based on assumptions of a designer who doesn't understand the user. Now that these tactile paintings exist, they can be used to make accessibility better in museums and art galleries, shining light on the issue of accessibility and providing an example of how this can be overcome using innovative technologies such as 3D printing. With new technologies there is always a chance that they can be applied in places that have not been considered before. Through discussing 3D printed tactile paintings, both test subjects discussed generally how technologies of all sorts fit into their lives, creating a contrast between the tactile paintings and other technologies.

Ultimately, the development of 3D printed tactile paintings was initiated to address accessibility issues that faced the visually impaired museum visitor. Through this investigation not only have we observed how this was done by developers but also what interactions existed in this process. How the technology is perceived and how it was eventually used has highlighted how far these tactile paintings have provided access to the visually impaired visitor.

5.4.2 The value of access and the paradox it presents

For many years what was communicated in the museum and the art gallery have been done so visually. Communication of knowledge through visual means has been administered in museums since they began to emerge in society as places of public knowledge (Dudley, 2009). The concept is still quite prevalent today as museums are still imagined as rooms with specimens behind glass cabinets and where touching is forbidden. In recent years the past exclusion of groups such as the visually impaired have been addressed and are constantly discussed in curation of exhibitions, on the boards of museums and at museum conferences. The acknowledgement that the environment of museums and art galleries are not constructed of the visually impaired creates a need for the technology to allow access for visually impaired visitors as museums are shifting to become open public places of knowledge for all citizens (Hetherington, 2000). This can also be linked to movements outside of museums, that have driven to make all areas of society accessible to all people. Hospitals, shopping centres, public places and even private sectors have all been enforced to allow access to the disabled. Designers and architects are now being taught design processes that involve the inclusion of all members of society. We have moved away from understanding disability as a medical condition and are moving towards understanding disability as the interaction between impairment and inaccessible environments. The problem is that many different forms of impairment exist, with a ranging degrees of impairment, impairments that are varying in visibility, that it is possible to even limit design by trying to design for all. The idea of universal design (Mace, 1985) and designing for all can sometimes trap designers in grouping users into categories that can limit the ways in which diverse users can be conceived. In the end the question therein lies, what actually is access, are their different types of access and what type of access are we striving for?

In relation to 3D printed tactile paintings, access is provided by building on an already exclusively visual system. Arguably, 3D printed tactile paintings do not provide access to the same experience that is provided to the visually abled visitor. This is only mediated and translated through 3D printed tactile paintings, similar to the access techniques that existed before it, such as audio guides and braille descriptions. The context of museums and art galleries are still fundamentally constructed on the dominance of sight and because of this 3D printed tactile paintings will never be able to provide complete access to this experience as the original artworks are still created with the visually abled viewer in mind. A step towards complete access would be to change the way visual art is created, no longer dominant on the visual but created for all 'viewers'[26] or all recipients. This is a common problem, not just in the context of museums but in society as a whole, visual dominance has resulted in an already existing system that excludes all those that are not modelled on the specific set of abilities that make up the standard individual. However, for the users, access is not about reforming how museums exist but in experiencing art in an unmediated form. Directly experiencing and connecting with art without a form of mediation is something that, at least for myself as a visually abled person, is taken for granted and is a very powerful experience. This is what 3D printed tactile models aim for, yet cannot fully provide.

One of the endeavours of this thesis was to identify the user's perception of the technology and in turn its relation to access. Through the interviews with the test subjects we found that there are a variety of ways that the technology can be perceived, even in such a small empirical sample. This emphasized the point that though the users of this technology can be identified as having a visual impairment, users should not be treated as one monolithic group. Even between the two test subjects I interviewed, what I found surprising was the vast differences in how they each personally perceived the technology. On one hand, one test subject viewed the technology under quite optimistic light, excited about how 3D printing can become the bridge to access to art that no other technology has yet to do. This test subject could see the use of the technology outside of the context of the museum and also a way to open up new domains that were not accessible to them before. For example, it was suddenly possible to engage with the microscopic world and the macroscopic world (objects too big or too small), which was not a possibility before. On the other hand, the other test subject felt that this technology was not a necessity and not necessarily something that will elicit much change in terms of access. They felt that having accessible art through 3D printed tactile paintings was a privilege that is not at the top of societies priorities compared to food deprivation around the world.

[26] Even language is dominated by sight; such as phrases like 'I see' to confirm that you understand.

Though these general perceptions of 3D printed tactile paintings differed, there were some shared thoughts of the technology. The most important being that the technology was an improvement from what has previously been provided to them before such as oral descriptions of the artworks by museum guides or through textual information provided through Braille. It was interesting to see that though both description of artworks and 3D printed tactile models are representations of the original artwork in some way, for test subjects, it was not the same. Even though both are representations and both are not the original artwork, what the test subjects saw as more valuable to was the ability to touch the 3D printed tactile models themselves. This direct engagement provided the test subjects with their own sense of agency without having to rely on another person's interpretation. The test subjects saw that the tactile models less of an interpretation, allowing them to experience the painting through their own sense directly without it being mediated through language. This allowed them to explore the painting in their own way, at their own speed and rhythm and the option to focus on elements of the painting they were drawn to personally. So for the test subjects, the 3D printed tactile paintings gave them access to more autonomy in the way they experienced art and for them this was a step closer to an unmediated experience of visual art.

5.5 Further Research

In retrospect, opening up this case study has been immensely enriching and interesting. Investigating a technology that touches a number of different areas of society has been challenging to say the least. However, it is these technologies that encompass a variety of different themes that end up being the most thought-provoking and surprising. I believe this thesis has provided at least one angle in the regards to accessibility and disability in museums and how technology addresses this issue. Though much has been covered in this thesis, further investigation into areas of the case study that were only briefly addressed would be beneficial in exploring the case study more thoroughly. There are a number of different tangents of this thesis that can be further researched such as a focus on 3D printing and designing for the disabled. In particular, further research into improving this technology has already begun with visual elements such as colour being one of the main focuses. It will be interesting to see how this process develops further.

From a research perspective, further investigation into accessibility in museums would be interesting to open up. Exploring how different practices and interactions within museums and surrounding museums enact accessibility could be beneficial. This thesis was limited to what was directly involved with the technology and not the construct of museums as a whole. Zooming out from this case study, could be useful not just in an STS context but also for museum studies and practices. Inquiry into the role of the museum can also further answer questions that have arisen from this thesis such as what are the pressures that face museums in acquiring technologies such as 3D printed tactile paintings? How are these pressures constructed and what are the politics surrounding these decisions?
For example, the shift in society's understanding of disability and also the increase in social equality has lead to a re-evaluation of a number of different systems that have been found not to provide access and equality to all. Funding initiatives from governments have increased as incentives for public systems such as museums to start addressing these issues. This, along with making sure that a museums reputation is kept clean from social or political scandal. Museums have become trusted places of public knowledge and for this to stay this way, museums have pressure to make sure that they open spaces to all publics.

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Figures

Figure 1. Picture of Original Painting of Madonna with the Christ Child and Saint John the Baptist (Madonna im Grünen) by Raphael and its Edge Image:

(left) Retrieved November 25,2014, from http://www.nwerle.at/KHM_Raffael_Madonna.htm

(right) Retrieved February 3, 2016, from https://youtu.be/SkbIqTrYSUk?t=52s (screen shot)

Figure 2. Height Depth arrows and Height Map

(left) Retrieve February 3, 2016, from https://youtu.be/SkbIqTrYSUk?t=1m40s (screen shot)

(right) Retrieved February 3, 2016, from https://youtu.be/SkbIqTrYSUk?t=1m52s (screen shot)

Figure 3. Layered depth diagram and Textured Relief model

(left) Retrieved November 25, 2014, from http://www.vrvis.at/presse/pressefotos-bilder/tactile-paintings/tactile-paintings-liniendiagramm-und-layered-depth-diagram-zu-detail-von-raffaels-madonna-im-gruenen-1505-oder-1506/image_view_fullscreen

(right) Retrieved November 25, 2014, from http://www.vrvis.at/presse/pressefotos-bilder/tactile-paintings/textured-relief-zu-raffaels-madonna-im-gruenen-1505-oder-1506/image_view_fullscreen

Figure 4. Scan of engraved hunting knife and Acrylic 3D model of the knife

(left) Retrieved February 16, 2016, from https://youtu.be/BX0BM-B6HzE?t=2m16s (screen shot)

(right) Retrieved February 16, 2016, from https://youtu.be/BX0BM-B6HzE?t=2m5s (screen shot)

Appendix

List of Abbreviations

2D	-	Two Dimensional
3D	-	Three Dimensional
ANT	-	Actor Network Theory
BBI	-	Bundes-Blindenerziehungsinstitut
CAM	-	Computer-Aided Manufacturing
CNC	-	Computer Numerical Control
CORD	-	Convention of the Rights of Persons with Disabilities
DDS	-	De Digitale Stad (Digital City of Amsterdam)
EEG	-	Electroencephalogram
FDM	-	Fused Deposition Modeling
ICT	-	Information and Communication Technologies
KHM	-	Kunsthistorisches Museum
MRI	-	Magnetic Resonance Image
QCA	-	Qualitative Content Analysis
SCOT	-	Social construction of technology
SIV	-	Scientific Imaging and Visualization
SLA	-	Stereolithography
SLS	-	Selective laser sintering
STS	-	Science and Technology Studies
UCD	-	User Centered Design
UN	-	United Nations
VRVIS	-	Zentrum für Virtual Reality und Visualisierung Forschungs-GmbH

Abstracts

Abstract (English)

One of the many issues that museums and art galleries face today as public spaces is the issue of accessibility. One of the roles of museums in society is providing access for all visitors to their exhibitions and artefacts regardless of age, education, language or disability. However, the museum as an educational institution and preserver of history has become established on a fundamentally visual notion. Museum experiences rely heavily on the visual sense, from observing artefacts behind glass to reading information packages off plaques and because of this has established inaccessibility for the visually impaired community. Museums have so far addressed this issue with audio guides, braille description and special guided tours. However, museum culture in recent years have begun to change, acknowledging that learning experiences can be improved through accessing knowledge through the other senses. For the visually impaired community, there has been an emphasis on touch. However, allowing access to touch can be difficult especially when dealing with fragile artefacts that are stored for conservation. This case study focuses on a technology that addresses this issue, 3D printed tactile paintings. In partnership with the Kunsthistorisches Museum in Vienna, VRvis, a visual computing research group based in Vienna has developed a process in which 2D artworks such as paintings are translated to produce 3D haptic images specially for the visually impaired visitor. Using STS approaches, this thesis focuses on how this technology was developed, the design practices, the user imaginaries that were present during development, how the users were involved in the process of development and how the context of disability influenced the design process. This technology is situated in a very fascinating context that finds the developer in a unique situation where they are designing for a specific group that they themselves can not subscribe to or experience, resulting in a very interesting self-awareness on their dependence on user input during the development phase. This case study explores this and offers a number of key observations surrounding these unique experiences.

Abstract (Deutsch)

Zugänglichkeit ist für Museen und Kunstgallerien eines der vielen Probleme der heutigen Zeit. Eine der gesellschaftlichen Rollen von Museen ist der uneingeschränkte Zugang zu Ausstellungen und Artefakten, ungeachtet des Alters, der Ausbildung, der Sprache oder möglicher Beeinträchtigungen der BesucherInnen. Dennoch gründen Museen als edukative Institutionen und Bewahrer der Geschichte im Visuellen. Museumserfahrungen stützen sich Großteils auf den Sehsinn, vom Beobachten hinter Glasscheiben bis hin zum Lesen von Informationen auf Schildern. Dadurch etablierte sich eine Unzugänglichkeit für die Gemeinschaft von Sehbeeinträchtigten. Bisher sind Museen diesem Problem mit Audio-Guides, Beschreibungen in Braille-Schrift und speziellen geführten Touren begegnet. Aber die Museumskultur hat sich in den letzten Jahren verändert. Man erkannte eine Verbesserung der Lernerfahrungen durch die Einbindung anderer Sinne. Für Sehbeeinträchtigte lag der Fokus bisher auf Berührung. Ein taktiler Zugang kann jedoch schwierig sein, gerade wenn es sich um fragile Artefakte handelt, welche zur Konservierung eingelagert sind. Die vorliegende Untersuchung widmet sich einer Technologie, welche dieses Problem adressiert: dreidimensional gedruckte, taktile Bilder. In der Zusammenarbeit mit dem Kunsthistorischen Museum in Wien hat VRvis – eine Forschungsgruppe im Bereich Visual Computing – einen Prozess entwickelt, welcher speziell für sehbeeinträchtigte BesucherInnen zweidimensionale Kunstwerke wie Gemälde in haptische, dreidimensionale Bilder übersetzt. Unter Verwendung spezifischer Zugänge der STS, untersucht diese Arbeit die Entwicklung dieser Technologie, die angewendeten Designpraktiken, die eingeflossenen Eindrücke und Erfahrungen der UserInnen, deren Einbindung in den Entwicklungsprozess und die Einflüsse der Beeinträchtigung auf den Designprozess selbst. Die Technologie ist in einem faszinierenden Kontext situiert, indem die EntwicklerInnen in der einzigartigen Position sind Produkte für eine spezifische Gruppe von Menschen zu designen, der sie selbst nicht angehören und deren Erfahrungen sie nicht teilen können. Durch ihre Abhängigkeit auf den Input der UserInnen entsteht ein bemerkenswertes Ichbewusstsein auf Seiten der EntwicklerInnen. Die vorliegende Fallstudie untersucht jene einzigartigen Erfahrungen und bietet eine Vielzahl von Schlüsselbeobachtungen.