MASTER THESIS

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Universal Design of ICT

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Universal Design of 3D interfaces

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Preface

Having the opportunity to work with this theme and genre of technology, interface and Universal Design has been extremely interesting and motivating and for that I am truly grateful to my supervisor Tor-Morten Grønli for presenting me with this topic. Others who helped med along the way were Anthony Giannoumis, BEKK consulting, my classmates as well as my friends and family who put up with me through the ups and downs of writing this paper.

Abstract

Three dimensional interfaces on two dimensional screens and platforms are getting more and more popular as a method to convey increasingly complex systems in an interactive, cognitively easier to understand manner (Petrobras, SpaceMaker, TechPubRolls etc.). The background for the research conducted in this paper is to try and meet this development by exposing accessibility issues and how to prevent or circumvent these.

The constant goal and motivation for this thesis was formulated as the problem statement "Improving and expanding upon User Experience and Universal Design considerations for 3D interface program development". In order to work towards this goal the question that had to be asked at every problem and consideration was "What design considerations should be emphasized in order to ensure the Accessibility of a 3D-based interface?" The problem statement and supporting research question proved to be a reliable guideline and constant problem that invited further investigation and testing as well as context for the answers uncovered.

This thesis aims to figure out best practice guidelines and expand the knowledge upon the Universal Design aspect of three dimensional interfaces. The dynamic nature and deep functionality of these types of products are inherently excluding in a significant amount of aspects at core level. Due to this a critical examination at all levels of interaction must be done in order to figure out how the development and design community can meet the needs of the users before this sort of technology and interface design becomes even more spread out.

The most important discovery, or discoveries, depending on personal classifications, would be that when developing and designing a three dimensional interface the utmost care must be done in order to decrease clutter and cognitive load on the screen in order to attribute as much mental attention as possible towards the 3D object and its abilities and functionality. In addition to this, and just as important, while maintaining a strong culture of interaction feedback and guidance, there should also be a tremendous amount of freedom for the user to specify and customize their interaction. The dynamic and layered functionality of a three dimensional system or interface is of such a complexity that different groups of users will have different preferred ways of interacting with it. By providing either a way of customizing user interaction or allowing the user to freely switch through different interaction modes

(that are tailored to meet user needs through exhaustive research) the user may feel more comfortable and even empowered in their use and ownership of the program. Several other findings were uncovered and will be expanded upon later in the paper. This thesis can with some confidence conclude that there is immense value in a properly developed and designed three dimensional product, but that it is extremely dependent on good research and thorough problematization in order to fulfill the potential it can and should provide. The best solutions may replace and improve existing solutions and open up for faster and more efficient interaction where there previously were none, few or insufficient solutions. If the knowledge uncovered in this thesis is disregarded, the same results considering improvement and replacement will be reached, but at the cost of excluding an unknown amount of participants while resulting in difficult to learn, frustrating to use systems. The pitfalls and potential risks of three dimensional solutions are great, but developed and designed properly, the value and power is far greater.

The questions uncovered and left unanswered are many and varied and will hopefully spur further investigation and research into the genre of three dimensional interfaces and its strengths and weaknesses.

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Introduction

This research paper will focus on 3D interfaces made with a User Experience and Universal Design focus. User Experience in the context of this particular paper means how the product should give the user a good sensation from interaction with the product. Considerations for this would be to make the app easy and pleasurable to use with a clear layout that guides the user without intruding in addition to giving the user a sense of freedom and enjoyment during the interaction process.
Universal Design in the context of three dimensional interfaces may be a difficult concept to incorporate in this particular genre. This thesis focuses on what designers and developers should be recommended to consider in order to ensure that three dimensional interfaces are accessible for use across all user groups. Finding ways to allow users with different interaction disabilities to satisfactorily use digital products with as little effort as the general population is the penultimate goal of Universal Design in the context of this particular thesis.
Starting with the app PainDroid made for Android, an application developed with the objective of allowing patients suffering from chronic pains and discomfort to their respective physicians in order to shorten the time patient and physician would have to spend figuring out where the issues lie. With color coded markup for the different general sorts of discomfort as well as quick select buttons for resetting position, undoing last input as well as completely resetting the process the product aims to be an easy and effective solution for all users. The product exists as a prototype on Android platforms at the time of this thesis.

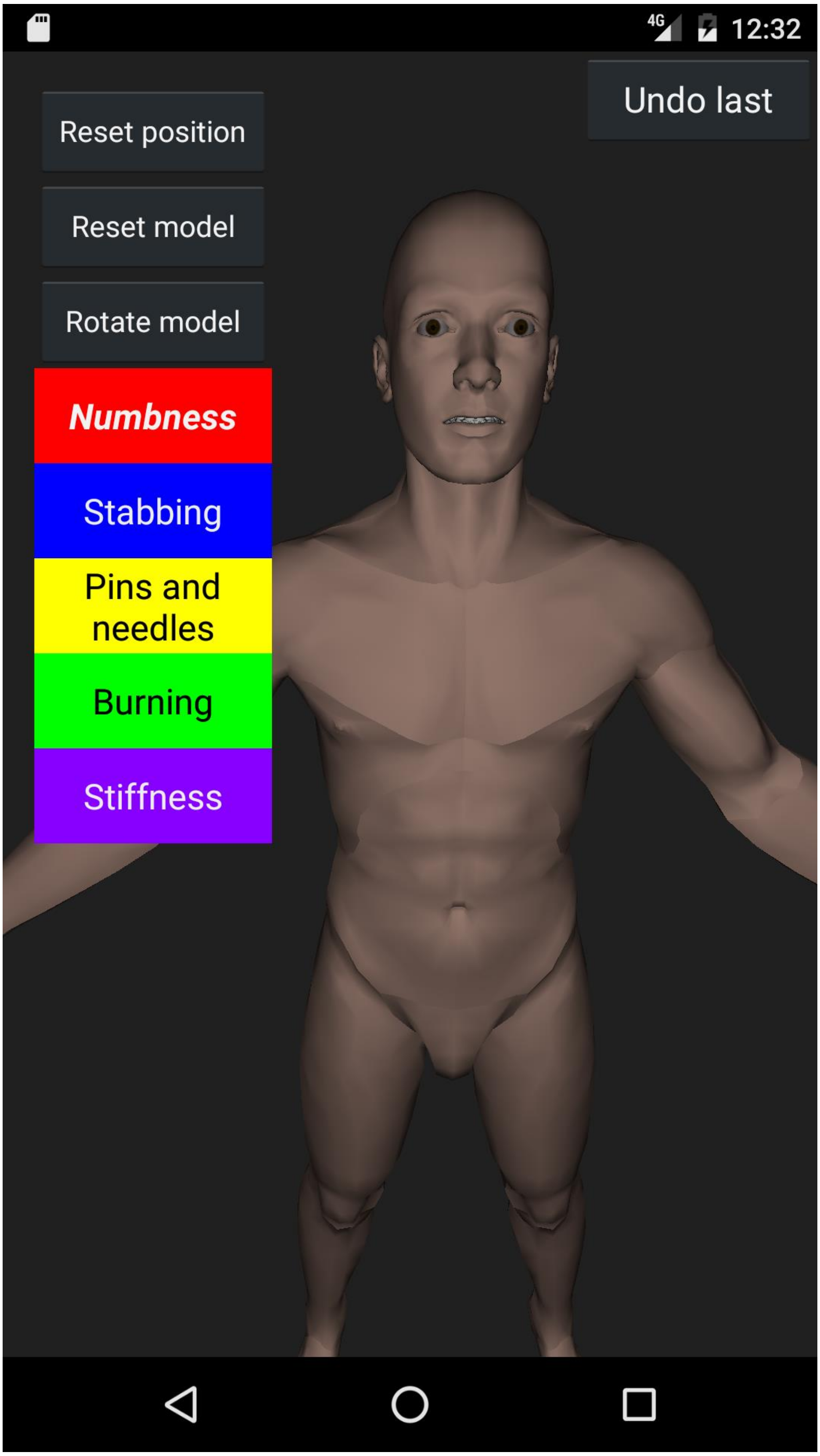

Figure 1: Screenshot of the PainDroid application.

The main goal is to thoroughly investigate the accessibility aspect of 3D objects on touch screens. Based on the paper "*PainDroid: an android-based virtual reality application for pain assessment." (Spyridonis, Hansen, Grønli, Ghinea)*, this thesis will focus on further developing the PainDroid application (henceforth mentioned as "the product") in a User Experience and Accessibility aspect.

The background research and development of the product was conducted in order to improve chronic pain registration in patients between sessions with physicians and doctors in order to improve doctor-patient time and make it easier to monitor development in the patient's condition. By putting the traditional "Adam" figure that is ordinarily used into a 3D object that the user could interact with, the researchers aimed to make it as intuitive and easy as possible for patients to monitor their own condition. The digitalization of patient metrics and other data also aims to decrease processing time and make it easier for medical personnel to maintain an overview of the patient's needs and treatment. This will also improve the patient's ability to gain an increased amount of control over their day to day condition and treatment progression. By giving the patients this overview and ability, the patient will feel a sense of ownership and collaboration to their own treatment process as well as the app.

Seeing as the product is already developed as a functioning prototype, most of the logistical groundwork as far as functionality goes was handily laid out. What remained to be done was to systematically improve and redevelop the User Interface, Universal Accessibility and general User Experience and conduct research in order to validate the choices and thus gain knowledge about the accessibility aspect of three dimensional interfaces.

Tests and research was done iteratively with a constantly revolving cycle of information gathering in order to build a temporary hypothesis that then could be tested through fragmented user tests (or action research) of individual components. Individual composite testing is not enough however as thorough investigation into the complete user cycle from start to finish also needs to be re-addressed from the ground up. Each test was revised and analyzed based on each individual user's feedback in order to establish a clear picture of the correlations between the sessions and zero in on the issues that needed to be addressed.

By basing every single test on hypotheses for each individual part of the system or the whole Use Case the objective was to improve every part of the user journey.

When the user journey in all its fragments and entireties had been addressed, tested, improved and tested again there was sufficient information uncovered to be able to draw estimates and conclusion on how three dimensional interfaces should be handled. All research on the UI and GUI provided valuable insight into the product’s quality as a whole while furthering both research, the quality of the product and the field of Universal Design in the direction of 3D technology.

Problem statement and Research Questions

The main focus of this research paper is to develop guidelines and uncover knowledge of how designers and developers should address accessibility issues in relation to three dimensional solutions. Thus the success criteria for this thesis lies inherent in the problem statement which is: “Improving and expanding upon User Experience and Universal Design considerations for 3D interface program development”. To be more specific, in order to consider the research conducted to be successful, there has to be a sense of value provided to the genre of 3D interfaces. This can be interface design considerations, how one should work with interaction barriers etc.

The User Experience and Universal Design aspect of 3D interfaces is something that should be addressed as early as possible with the emergence of this type of technology into products available to the general public.

In order to address these issues and catch up to technological advancement usability-wise, this thesis will strive towards bettering the User Experience and Universal Design of 3D based interfaces and attempt to aid future researchers by obtaining a solid foundation of the basic interaction and usability considerations in this context.

(Zhang et.al. 2016) states how the emergence of mobile health services rely heavily on an immediate positive response from Users in order to achieve User acceptance of emerging solutions. Considering the problem statement from an Accessibility perspective as well as the UX perspective in relation to User Acceptance the focus is determined to revolve around a user-centered research process.

With this in mind, the research questions went through several iterations for every single circulation through the research process. The only constant that guided the ever changing questions that demanded answers throughout the research and design process was the Research Question of: “What design considerations should be emphasized in order to ensure the Accessibility of a 3D-based interface?” Almost a problem statement in of itself, it encapsulates all the minor temporary research questions that arose when an awareness of an issue presented itself. Rather than describing each individual one, the focus was always to figure out what was needed in order to ensure Universal Accessibility of three dimensional products.

Literature

Going into the first phase of the Master’s Thesis it became apparent that there has been done surprisingly little research on 3D technology in a UX/Universal Design perspective. The ones that were applicable that uncovered in the preliminary phase are included in the review below. While 3D-specific research papers were hard to come by, there is a tremendous amount of general Usability, User Experience and Universal design research papers and literature out there that I will most likely look to for guidance during my work. These books and videos will be mentioned in the sources while not mentioned in the actual review and analysis due to them being all-round applicable and not directly applicable to the thesis in the same way as the papers.
During the literature search a pattern started to emerge going through keywords as 3D, User Experience, Universal Design, Cross Platform, Multimodal interfaces, Usability, Visualization, development, user testing, user research, disabilities and more, all the while cross-referencing, searching through every combination as well as the AND/OR parameters. This led to finding a trend in the most applicable and recent studies as well as where to find them. The search proved most effective by going through Springer, Bibsys, Oria and Sciencedirect while peripheral sources from Vimeo, various books with a general relevance were found or were already in possession. The peripheral applicable sources are not included in this literature review and analysis, but are rather mentioned in the sources for further referencing and to show where the inspiration for the direction of the paper is found.
The following segment is split up in two parts; “literature review” and “literature analysis”. In the review part the focus will be on the contents of the paper in a brief short version explaining what it is about, what studies were conducted and the results. A short description will then be given of how each paper relates to the thesis individually and lastly list the main points that will be kept in mind while working on the project.
Literature analysis will contain a comprehensive discussion about the papers that were found and read and how they relate to one another and are helping me establish a platform for continued research.

Literature review

In this section the literature that was uncovered and estimated to provide preliminary will be outlined in order to ascertain the background of the estimations and assumptions that laid the groundwork for this thesis. The research found was varied both in category and origin. At some point an individual point of personal praise made on an online messaging board (https://www.reddit.com/r/Overwatch/comments/4kwjfe/thank_you_blizzard_for_allowing_me_to_snipe_for/) (14.11.2016) helped with providing a representation of the value that could potentially be found in this research if conducted properly.

Methodology literature

"Design Science Research in Information Systems" *(Vaishnavi, Kuechler), (2015 (most recent edit))*

A paper being continuously updated aiming to explore, explain and expand upon the topic of how Information System designers and developers have to work with their projects in order to reach a satisfying conclusion. Different viewpoints, how to rate, provide and maintain good value in both scientific and private communities as well as how to recognize weaknesses and strengths in your own method is exhaustively expanded upon.

The thorough examination, explanation and evaluation that Vaishnavi and Kuechler does in their dynamic paper seeks to perfect the design process of innovative artifacts. This further leads to analyzing the use and performance of the aforementioned artifacts in order to use the data in a pursuit of improvement and understanding of the inherent behavior between user and machine, program or device.

Applying research to thesis:

Due to the (in the paper's own words) novel nature of the program (artifact) that this research paper will be based upon, Design Science Research and it's professed methodology makes the most sense to employ. Lean methodology is heavily influenced by this method and is an integral part of this.

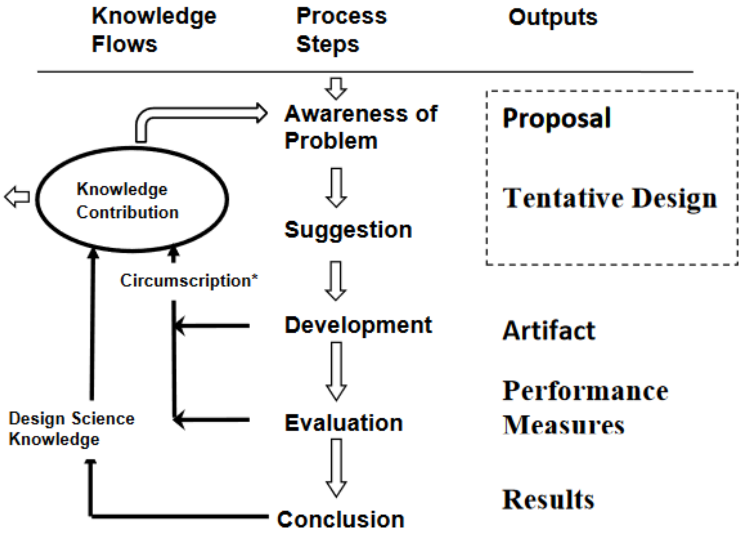

Figure 2: The process description of Design Science research

Seeing as the previously anticipated method that would have to be employed for this thesis was in fact the Lean Method, the Design Science Research method explains the process in a more comprehensive and better structured manner. The concept of recognizing issues, setting out to address and remove these and in turn attempting to uncover more issues circulatory is already covered by the Lean UX method. The advantage that DSR has on this is the way you structure your research and categorize the uncovered data. For example the way the researcher analyses the uncovered knowledge post test in DSR is extremely precise in the way the knowledge is then categorized. There is little knowledge or further questions that are discounted. The information is viewed in context of how it can be applied to the specific research project in question as well as if there should be future research done on the uncovered information further down the line rather than if it should be conducted in tandem with what the current research is trying to figure out or solve.

Applying research to thesis:

The methodology and, more importantly, the way you analyze, categorize and make use of all uncovered information can theoretically provide the research conducted on PainDroid in order to solve the problem statement right now as well as provide good basis for further projects and researchers due to what was uncovered, but not expanded upon.

Alternative interaction models

“Making Gestural Interaction Accessible to Visually Impaired People” (Brock, Truillet, Oriola and Jouffrais), (2014) This paper explores the poor accessibility aspect of the commonly used capacitive touch screen in regards to users with visual impairment and how gestural interaction might elevate the user friendliness and experience.
The paper highlights the issues users with visual impairments face when interacting with touch screens: The biggest difference between touch screens and regular tactile interaction is that there is little consequential feedback as to WHAT you are touching on the screen and where to go for the next action. Furthermore, the fact that there interface is subject to change makes it difficult to remember objective completion, as well as making visually impaired users almost afraid of accidentally activating functions that they do not wish to activate.
The paper explores existing solutions to gestural interaction as an answer to these pain-points as well as making suggestions and theories for the road ahead as far as better solutions and theories are concerned.
The methods deployed to verify the prototype built in this paper is severely limited due to the fact that they only had time to conduct pre-tests in order to make a proof of concept prototype. By testing the prototype on a blind researcher participating in the development, who also had previous experience with the foregoing prototype, the returned data is not able to provide actually valuable user feedback.
Nevertheless, the proof of concept was established by the researchers with a clear focus on the technical requirements of the product in order to preventively meet the more logistical difficulties that might arise. Further testing has to be conducted on a larger sample of users in order to satisfyingly validate the prototype. Even if the testing itself is somewhat lacking, the research, thought and development of the first version of the prototype provides valuable insight into how a gestural interfaces should meet the requirements of users with blindness.

Applying research to thesis:

Further studying alternative ways to interact with touch screens and other traditional interfaces will supply me with a broader platform to work with when estimating, testing and evaluating different approaches to develop alternative interaction models for disabled users.

The different approaches and research done in this particular paper pertains to the theories and possibilities of solutions I might consider going further with my research. This paper, in addition to the other papers I have found, will help me save time and resources going forward as I can build my theories on the previous work conducted as well as further pinpointing solutions and designs towards a more precise end product.

Most notable aspects of paper going forward:

Most advanced (for the moment) accessible gestural interaction is currently provided by Apple's voiceover Screen Reader. As far as feedback goes, it is the most enabling software for visually impaired users to navigate a touch-based interface.

User customization is an opportunity for the user to tailor the interface especially to their information and interaction needs.

Specific gestural input should be programmed into a gesture based solution to enable user learning especially tailored to accommodate the program in question's functionality.

"Touch screen performance by individuals with and without motor control disabilities" (Chen, Savage, Chourasia, Wiegmann, Sesto), (2014)

This research paper envisions to investigate the effects of button and gap size on users with various motoric abilities and disabilities and how different layouts and solutions affect performance. Motivations for the paper lies in the increase of touch based devices in the world and the wish to make touch based interfaces more accessible for users with motoric disabilities.

The tests conducted by the researchers uncovered that button size affects goal completion significantly while gap size made little to no difference in task efficiency.

Paper shows that touch screen interaction by direct finger input is cognitively easy to learn. Inexperienced users found it to be an easily taught and applied way to interact with the device.

As far as motoric disabilities goes, the research aims to uncover how it is to make use of touch screens with this particular challenge.

The study conducted tests on a grand total of 53 participants, one control group of 15 users without motor control disabilities and 38 participants with motor control disabilities. The age and gender distribution was similar between groups in order to get the most viable results. The method employed for statistical contextualization was in the form of two questionnaires. The first questionnaire was conducted in order to determine the statistics concerning age, diagnosis, how long the users had been living with the diagnosis, living arrangements as well as questions about each participant's experience with day to day technology use.

For design evaluation the researchers conducted user experience testing in a completion time/interaction accuracy testing context to map out the ideal button sizes. The ideal sizes were measured up against button tap misses (defined as a touch that landed outside of the intended area), error ratings (defined as a touch which resulted in activating the wrong button) and completion timing (measured in trials that had no "miss" or "error" interactions).

The gathered data from the testing group and the control group was then measured in order to draw contextual coherences between the testing data.

The method used for data gathering in this paper employs a rather large sample of testers in order to prove the statistical relations between buttons size and task completion effectiveness. The correlations between successfully completed tasks and button sizes is easily reproduced if one would wish for it and gives valuable insight for developers who wish to achieve maximum effect from their user interface.

Applying research to thesis:

Even though significant goal completion performance is measured during the research, the importance of considering decent trade-offs in order to accommodate smaller screens needs to be pertained.

Most notable aspects of paper going forward:

Disabilities vastly increased "miss" percentage, increasing button sizes remedied this issue somewhat.

Spacing between interactive buttons make little difference to task completion speed or miss-clicks for regular users, but has positive effects for users with motoric disabilities.

Plateaus for improvement were reached at 20mm squared button size without significant improvement for sizes above this. Even though users without disabilities were unaffected by button spacing, a vast majority preferred the 3mm gap size between the buttons.

“Accessible user interface support for multi-device ubiquitous applications: Architectural modifiability considerations.” (Desruelle, Isenberg, Botsikas, Vergori, Gielen), (2016)

This paper, contrary to the previously reviewed, explores the possibility of developing web applications/interfaces that can be easily implemented and adapted to different physical devices regardless of screen size and other limitations.

The modifiability of software is elaborately explained and expanded upon with three main tactics developers and designers should implement to make their software as modifiable and adaptable as possible.

Platform Independent Model (PIM) is highlighted as an abstract sketch of the system that can in turn be used to specify the technical needs for a Platform Specific Model (PSM). For the User Interface aspect the paper elaborates on what they call the CAMELEON Reference Framework (CRF) that focuses on a context-oriented UI-development process. This process focuses on environmental context, user context and the platform the program is deployed on’s context.

Paper revolves around the Webinos ubiquitous for web-based applications first and foremost with development and evaluation of the platform itself as well as further work as the main focus of the paper.

Being more focused on the technological requirements and the logistics necessary for cross-platform development, this paper has no verification towards users. The researchers tested their platform in-house with case studies across a multitude of different platforms. More than anything, the tests prove that true cross-platform development is possible to attain with little to no difference between the different platforms as far as user interface design and architecture goes. As this paper is more wired towards providing a cross-platform development tool, it is not dependent on user input as this is a consideration better preserved for the individual projects that employs the WEBINOS platform for their product. The research done in the paper in order to prove a need for cross-platform products is however sound and shows that the need for products to seamlessly transition between platforms is a very real one.

Applying research to thesis:

The Webinos platform itself is not necessarily directly applicable to my thesis. The approaches and mindset that led to the inception of the Webinos idea, however, is absolutely something to further build on.

The approach of having an abstract user interface that is easily modifiable and evolutionary adaptable is deeply rooted in user needs and context and recommends good, holistic mindsets. This will be valuable in order to achieve an agile base design that is easily modified for different screen sizes, platforms and user needs for development purposes and the product itself.

Most notable aspects of paper going forward:

Platform independent models, both for design and code.

Platform specific models based on user context and needs.

“Evaluating the Usability on Multimodal Interfaces: A case study on tablets applications” (Neto, Campos), (2014)

Neto & Campos focus on the growing share that haptic tablets have on the household technology market and the need for good multimodal design in order to fulfill the user’s need of continuity in their day-to-day human-computer-interaction on different surfaces.

The exact point of interest in this particular paper is that they aim to seek out certain models and styles for the different modalities that are slowly emerging. The different groups of heuristics when interacting with touch-oriented surfaces are clearly laid out and weighed against the more recent modes of interaction as for example speech-based input.

The new heuristics proposed in this paper are: (1) Visibility and feedback, (2) compatibility, (3) control and freedom, (4) consistency, (5) Error prevention, (6) Minimum actions, (7) Flexibility of use, (8) Organized content, (9) Error management, (10) Direct manipulation, (11) Changes of orientation and (12) Human Range.

After testing the new heuristic test criteria in a development setting with 3 groups of professional designers working on an app development project the researchers found that for touch-specific surfaces (phones, tablets etc.) the 12 new evaluators were better suited for this particular setting.

The new forms of interaction emerging in day-to-day technologies need new forms of design evaluation. The proposed criteria of this paper showed promise, but the researchers suggest that overly experienced users may be too accustomed to the traditional criteria. Further tests are suggested with less experienced designers to find out if this is the case.

The paper nevertheless shows that the heuristic test criteria for multimodal interaction has a certain advantage over the more desktop-oriented heuristic criteria previously employed by designers.

Applying research to thesis:

The tests, proposals and research done in this paper will significantly help me to establish good, well founded criteria for whether or not the solutions proposed in my own paper measure up successfully. The focus on multimodal interaction and the different ways a user can interact with a product will boost my hypothesis for testing and design going forward. Seeing as the nature of the product, the design, goal and targeted user group is based on multiple needs and affordances the research conducted in this thesis will have to find new ways to evaluate decisions and achievements compared to projects that have been previously done.

Most notable aspects of paper going forward:

New criteria for design success, new approaches to test evaluation and the value of multi-platform oriented design research in product design and development.

3D interface centered literature

“The Formulations and Visualization of 3D avatar Design, Including Three Basic Theoretical Elements: Aesthetic, User Experience and Psychology.”

(Photiadis, Zaphiris), (2014)

This research explains and looks into the emotional attachment users have to self-defined avatars, the psychology behind and the user satisfaction in completing tasks with a digital “version” of themselves. While not furthering the research in question significantly, the paper gathers a plethora of resources and guidelines for developers to keep in mind when working with 3D-visualized objects and how these pertain to the user.

For proof, the paper exhaustively examining different research papers done in HCI, psychology and User Experience. The researcher theorize that the ability to customize an avatar or a character in an interactive product will increase ownership and affiliation with the product and its core function. This also leads to a greater forming of habitual interaction and increases the user’s experience with, and knowledge of, the product.

Applying research to thesis:

While not directly applicable, as the paper first and foremost focus on the gaming aspect of 3D based avatars, the guidelines and psychological pleasure-points of a personalized avatar is something to consider going forward with the project.
In laying the groundwork for further design decision and research on this, I should consider these (to me) important questions: Should the user be able to customize their avatar in-app? (Would a wheelchair-bound user prefer an avatar that is in a wheelchair, would a female user prefer a female avatar?). If so, would this significantly improve the User Experience and effectiveness of the app's functionality or would it lead to bloating and decrease performance unnecessarily? Would increased personalization be a necessary part of improving the product for the user in particular or would it just increase the "sales" aspect of the product in a commercial sense?
Finding out this as early on as possible will save a lot of work later on as well as lead to a greater commercial success depending on the results of this particular point of research.

Most notable aspects of paper going forward:

User well-being, user satisfaction, product pleasure/User Experience.

"Usability testing of a 3D touch screen kiosk system for way-finding."

(Tüzün, Telli, Ahr), (2016)

A research group in Turkey set out to figure out usability issues with a 3D based interface for wayfinding in shopping malls. By conducting standardized user tests on the wayfinding "kiosks" as they refer to, they were able to uncover interesting data about user interaction models with new interfaces and devices.
While the study itself is not particularly spectacular or revolutionary, it builds a foundation for usability testing of 3D interfaces for the years to come. As the technology gets more and more implemented in day-to-day gadgets and interfaces, the need for good design- and testing standards will become more and more apparent.
By making use of the more traditional usability test method, in the cycle of testing, the researchers continually evaluated and fixed the flaws that were uncovered. The researchers employed the 5-point Likert scale in order to evaluate user feedback. This method is a bit leading as far as user feedback goes as it may heavily influence the finer points of the users' opinions and responses as to whether or not they were properly satisfied with the experience. The Likert scale provides a certain statistically

strong foundation for further theorization and good hard numbers to prove what needs to be improved and why. The point still remains that a more exhaustive, qualitative approach to gather user feedback might have given the researchers more poignant information to work with in order to provide the best product possible. The group was able to uncover that for the most part, usability testing techniques does not differ all that much between 2D and 3D interfaces. The same pre-determining probing by the user based off of his or her’s previous experience with similar products (Dix, A., Finlay, J., Abowd, G. D., & Beale, R. (2004)).

Applying research to thesis:

By looking at the techniques deployed by *(Tüzün, Telli, Ahr),* I can cross-reference their testing choices with other established works of user testing to develop a solid and valuable testing regime for the thesis moving forward into phase two and three. The diverse nature of the test participants called on for research provide a representative assessment of the likely user groups for the program I will work with. The 3D nature of the program researched in this paper (although for an architectural layout rather than an interactive model) is proof that the value of my research will be applicable in other areas. Just like this paper was applicable to mine.

Most notable aspects of paper going forward:

The way the tests were conducted. There is little adjustment needed for a regular user tests of 3D-based interfaces compared to “traditional” user testing. Given the nature of the prospective users of the program I will work with however, the test environments may be afflicted. This will be a major part of the next phase going forward and an interesting point to expand upon.

“The Usability Evaluation of Web-based 3D medical Image Visualization”

(Settapat, Achalakul, Okhura), (2011)

This study aims at investigating whether or not there is a significant gain in employing 3D-based images and visualization techniques in medical fields. Particularly in medical revision and e-learning settings, the paper employs a web-based medical image visualization program and compares it to a traditional 2D program.

Test subjects were 10 medicine students and two MD-level lecturers.

For measuring satisfaction levels and User Experience the researchers enabled a Likert 5-scale questionnaire.

Based on the conducted tests and feedback from the users the researchers conclude that the 3D visualization techniques are a better way to teach and visualize biomedical images for students in learning scenarios and possible for medical professionals as well.

Applying research to thesis:

This paper specifically tests user satisfaction, User Experience and efficiency in regards to 3D visualized medical images. This makes the result highly attractive to my thesis and research as it shows that there is an actual need for 3D visualization in medical fields, at least on the practitioner side.

The results of the user tests are based on a somewhat “guided” test framework as the Likert scale puts the user feedback in a situation of “closed” feedback where the feedback is limited to the different alternatives proposed by the Likert-scale. This leads to the feedback being what someone could say is less valuable as the nuances views of the user does not come to light.

A more observation-based user experience test would uncover a lot of deeper feedback and patterns in the user interaction and would possibly be a better way to uncover and address possible problems. The numbers and results uncovered in this research paper is however valuable nonetheless even if the results needs to be tested during the work with the upcoming project in order to validate and cements its results for citation.

Most notable aspects of paper going forward:

User Experience rating increases with 3D, no significant increase in goal completion or speed.

Information perception accuracy increased with 3D, better visualization with 3D. No difference in familiarity and user friendliness. Desire and pleasure increase with 3D over 2D.

Further research and observations needs to be conducted in order to validate and make sure that this quantitative data measures up across different solutions as well as 3D visualized interfaces in general.

“Usability Tests for Improvement of 3D Navigation in Multiscale Environments”
(Andrade, Trindade, Silva, Raposo, Barbosa), (2011)

This paper conducts user research on both experienced and inexperienced users of 3D navigational interfaces in order to validate the user friendly aspect of a navigational software for oil rig landscapes.

The different modes of auto-focus and camera pivoting are the main points of interest for the researchers and they strive to gain a better understanding of which of these are the ideal modes for the user to employ.

The tests shows the significant difference in experienced users vs. inexperienced users as the paper shows that digital 3D interaction is not yet a natural interaction model for most user groups.

Through the user testing, the researchers found out that the users with little to no experience benefited heavily from various grades of restriction as far as interaction customization went. There were certain areas where the users wished for customization; like scrolling speed and other non-critical functions. These were areas where the users did not fear “messing up” as they rather tailored the speed of transition and scrolling rather than field of view and camera focus.

The experienced users proved to prefer having the ability to be able to customize their entire interaction process in order to freely choose what to automate and not.

Zooming and landscape collision was also a major concern for the researchers as inexperienced users might get lost “inside” walls and the like, without being able to orientate themselves in order to move the viewpoint out again.

In order to circumvent this, the researcher placed a varied collision setting in the program in order to stop the user from going through walls and other thick obstacles on the map. Smaller objects were placed without collision detection. This proved to lessen user disorientation while browsing through the navigational interface.

Applying research to thesis:

The research done in this paper, particularly its focus on inexperienced end-users, unit collision in the 3D environment as well as camera focusing and pinpointing pertains directly to the planned research going forward with the project.

Accommodating first time users with a positive, easy to learn experience from the start is critical for the success of a Universally Designed system. Users with little experience or users with interaction disabilities need to feel like they are in control while not being able to distort their own interaction by messing up object focus or camera pivoting.

This paper saves me from repeating the mistakes the researchers were able to fix during their work and allows me to try and address this issue and fix it even before going into the usability testing.

Most notable aspects of paper going forward:

First time user accommodation. The interface needs to be as welcoming and easy to understand as possible for first time users in order to avoid frustration. By doing this the user (both patient and medical personnel) will be less likely to write off the product and actually employ it in their treatment.

Camera focusing and pivoting on 3D objects. Image clarity, rendering and object collision proved a major point of this particular research paper. It remains to be seen how this may impact the interface during the project as it is not a question of landscape, but rather a zoom function. As far as collision and pivoting goes, the sensitivity needs to be low enough in order to help the user select the correct area and high enough to let them manipulate the object in a satisfactory manner. The object should most likely be solid as there is little need for the user to go “through” the object and situated at the middle of the screen as a focal point. This will need to be tested and proven.

User Interface customization. This aspect of the program needs to be carefully tested and investigated. The user might have certain wishes for their personal interface customization, but how extensive should these options be and how easily should these changes be to implement for them? This is valuable information that needs to be uncovered as early as possible for implementation purposes.

Methodology

Due to the fact that 3D interfaces have not yet been properly expanded upon there were a lack of previous works to establish my hypotheses on, my first set of establishing tests as well as the tests I deployed to validate my hypotheses were qualitative.

There was of course some research done on the usability aspect of 3D interfaces and products *(Andrade, Trindade, Silva, Raposo, Barbosa), (2011), (Settapat, Achalakul, Okhura), (2011), (Tüzün, Telli, Ahr), (2016),* but not any research done in order to prove the Accessibility needs of such elaborate interface solutions. Based on this, in order to build as strong a foundation as possible for my theories I had to build a profound understanding of edge users and their needs and wants in regards to dynamic 3D interface interaction.

When preparing for each test, there would have to be a significant understanding and awareness of possible problems and issues that would need to be addressed in such a way that it would be possible to single out barriers and pain points. After establishing the aforementioned understanding of the problems and barriers there would be a good foundation to implement suggestions in the form of changes or additions to the product in order to attempt to consolidate the uncovered issues. After implementing the proposed changes in order to assuage the complaints and feedback pertaining to general and specialized use the prototype could once again go through tests and research. Based on the subsequent feedback and test results there would be sufficient grounds to evaluate the uncovered information after each test and cycle in order to reach a conclusion. Further in-depth descriptions of how the tests were planned and organized to progress will follow further down in the chapter. Throughout the project the method employed was Design Science Research. By constantly focusing on the known issues in front of the researcher in order to fix them, while continuously using the uncovered information provided in this process to apply more knowledge and understanding to the research question at hand a revolving research cycle was achieved. The constant cycle of awareness, suggestions, development, evaluation and conclusion provided an excellent structure in a project with little to no previous work to draw on (see literature review).

For the purposes of my research I decided to focus on a large amount of qualitative user research and feedback. The reasons backing up my decision are several.

The first point of order before going deeper into the problem was considered to be to ascertain the nature of interaction with three dimensional interfaces. In order to understand the problem areas, pain points, strengths and weaknesses of this particular genre there was a need to figure out the where, what, why and how that forms the background of said strengths and weaknesses. In Universal Design there are logically enough some common ground for all projects, as well as with the field of User Experience Design that allow me to make certain assumptions. These assumptions had to be verified though, in order to figure out where the User encounters certain issues, why this issue arises, what the background for this issue is and finally how to address and solve this issue.

For such uncharted territory as my chosen technology has proven to be there was not enough to go on to produce good, valuable quantitative questionnaires or observations. There’s no guiding sense of shortcomings or previous research done in order to properly formulate good questionnaires regarding use. Combining this with no real area to gather User Interaction metrics either (this in particular due to my prototype not yet being open to the public) there was little to no statistical data or feedback that I could build assumptions to prove or disprove my assumptions on.

As a direct result of this I chose to deploy proper qualitative investigations and observe how both regular users and fringe users would operate this interface in the wild.

The strong side to this approach is that I can observe the User in their interaction with the prototype as well as tailoring my research questions specifically to understand and uncover pain points with either the application as a whole or parts of it. This approach also allows for a rapid “test, implement, test” cycle which in an ideal situation will allow me to extract as much precise and high value feedback as possible.

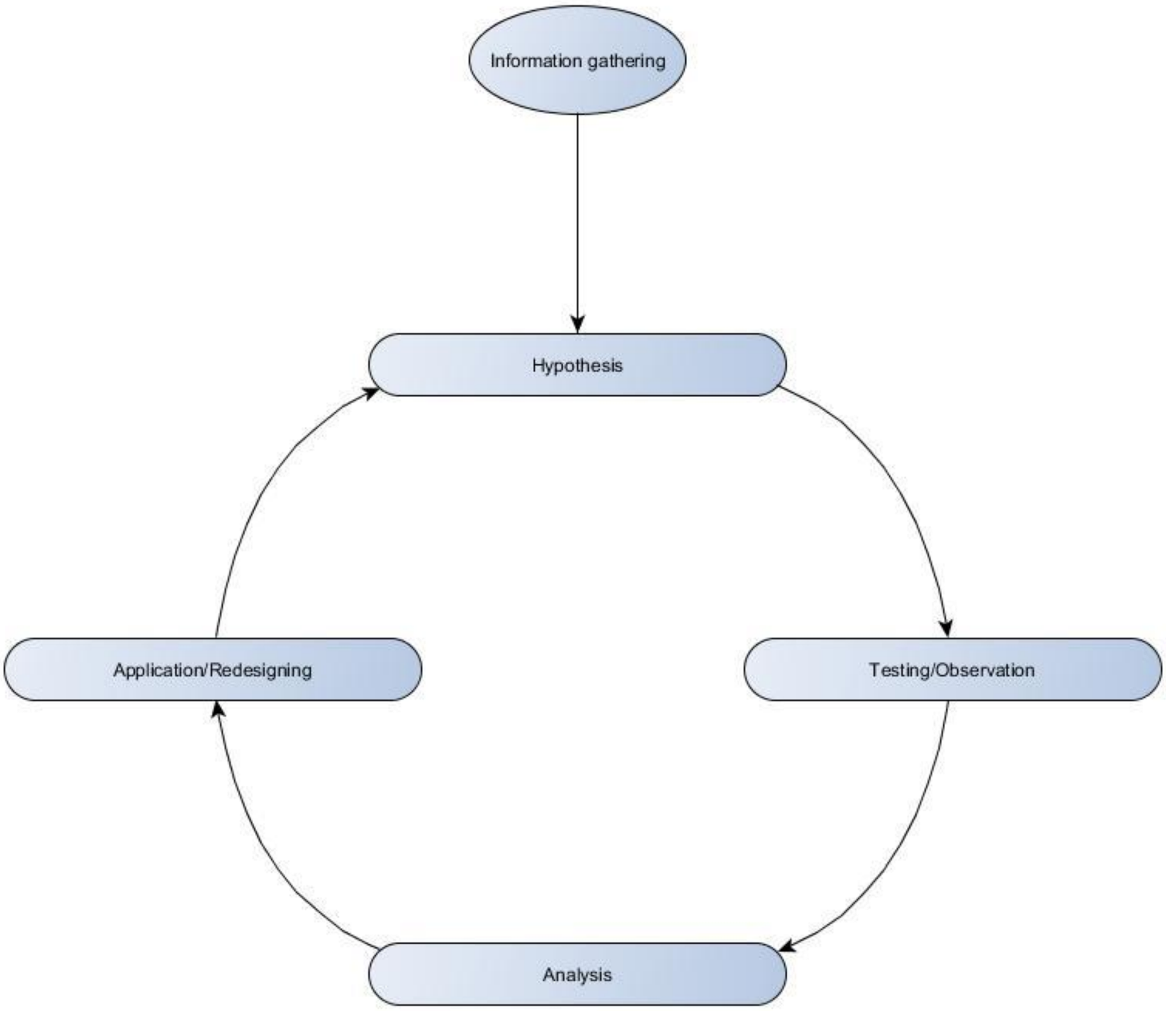

Figure 3: a graphic explaining the cycle of information gathering, hypothesizing, and evaluation of the hypothesis that was employed for the duration of this thesis.

With the groundwork laid by the iterative testing and research during the fall semester of 2016, the next part of the project could be conducted as effectively as possible. The preliminary research conducted during the fall semester enabled me to establish good, precise hypotheses in order to precisely test pertinent areas of use in order to pinpoint problem areas users have as well as formulate possible solutions.

Ethical considerations

Qualitative research poses several potential ethical issues concerning how data is gathered, how much data about the User is portrayed and how comfortable the User is with the information that gets recorded. *(Sanjari et. al., 2014)*.

I decided early on that there was no need to keep extensive data on personal information. The only information User Experience testing really need is the information yielded by the test itself and subsequent analysis. It is by and large the same for Accessibility Testing. The information regarding the users involved in this type of test does not need to unnecessarily entail any sort of information about the users themselves other than the fact that they will be considered “users” and will provide conducted research with good feedback.
By rendering the test participants completely anonymous I theorize that feedback will be more abundant and specific in the way it is relayed back to me. My theory also extended to the hope that more people, particularly in the “fringe user” category would be more comfortable participating in the tests.

In order to ensure that every single participant in my User Acceptance Testing and Fringe User Testing felt completely free of pressure, recognition or any sort of stigmatization at later stages I had to ensure that they were absolutely anonymous. This anonymity would be retained in how they were referred to in both my Research as well as my Analysis and recollection later on.
All participants received a letter of confidentiality before User Testing and observation was conducted:

“Confidentiality statement:

This confidentiality statement is made in relation to the master’s thesis of Sindre Säfvenbom in order to ensure the participants in its qualitative study that no information regarding their localization, personal information, physical, intellectual or cognitive information will be stored for any purpose.
These following questions and subsequent observation, analysis and considerations will always treat the participant as a non-descript user with certain contextual specifications. These contextual specifications will only state whether or not the test is done in order to determine general user satisfaction or fringe user satisfaction. Time, localization, gender and all other factors does not factor in here.
Participant will at all times be referred to as “User” or “users” in plural.

This statement is made in order to guarantee the confidentiality of the User at all points over the course of the research that will be conducted and is scheduled to conclude in June 2017.”

The reason for this is that except for the statement that the Users involved were considered “regular” or “fringe”, there would be no way of backtracking them as far as their input or views go.
As a result the participants actually showed immense relief at being completely anonymous and stated that it freed them up to speak their minds and concerns in regards to the prototype and its interface. The fringe users in particular were overwhelmingly positive to this approach as it removed any precognitions they might have had about the test being performed on them rather than by them. Several of the fringe users stated that they had initial inhibitions about participating in the research as they were used to performing various tests or examinations due to their age, cognitive abilities, physical abilities or loss of vision. By fully anonymizing the tests they fully realized that the tests was performed in order to improve the prototype and not in order to chart how “bad” they were at interacting with technology.

Research and Testing, preliminary, 2016

In order to ensure a way to cross reference results between iterations and adjustments to the interface, the same set of questions was deployed at each session of user testing. This was made possible due to the limited range of functionality the prototype has while also ensuring as large a range of different interactions and problems as possible for the user to experience. The follow up questions would attempt to pinpoint or expand where there would be considered a need for it and ensured the value of each test as they were carried out.
Test questions as they were asked during the research phase:

1. Please describe your first impression, what do you see, what stands out the most to you?
   1.1 *Situationally dependent follow up.*

2. Without doing anything, how do you expect the interface to react to your input?
3. Task: Please register a light sense of “pins and needles” in the lower back of the mannequin. (think-aloud protocol)
4. Please reset the input.
5. Task: Please register a sensation of your choice in the upper areas of the body (shoulders, neck, face, head)
6. Please register a sports related injury in the knee or feet, it can be upper, lower, back or front.
7. Please reset the mannequin position.

Situationally dependent follow up inquiries if necessary.

These questions were specifically developed in order to get a good picture of the existing prototype in its entirety. From start to finish, by observing User assumptions about available functionality I could gather information on where the Interface fell short in terms of labeling, available interaction areas and what elements caught their attention.
The secondary questions was put in place in order to charter the users’ expectations of interaction feedback before engaging in any meaningful activities. This “at a

glance” investigation proved to highlight a lot of problems and areas of improvement with the interactive part of the prototype as well as how much feedback would be relayed back to the user.

The first interactive task put the user on the track of a full User Story from beginning to end. PainDroid’s main functionality is, after all the registration of pain and discomfort. The think-aloud protocol was enabled in order to make sure that the users’ actions had context due to them voicing their reasons for their chosen interaction. The think-aloud protocol was maintained throughout the entire User Test of course, the mentioning of it is more for reminding purposes than anything else.

The task to reset input was put there just to see which of the different ways of removing input the users chose to go with. For design purposes this was deemed highly important in order to make educated assumptions as to which functionality to improve and keep, which functionalities to remove or if all the different ways of performing this action should be kept and improved or even left as is.

The fifth task was developed to allow the user freedom of movement around in the program, leaving them open to decide which discomfort to choose, where to put it in as well as allowing me to observe how they would navigate around the 3D mannequin. The goal of this task was to verify the zoom functionality as well as the rotating functionality and turned out to be a test of the accuracy of the pain indicators.

Ironically, the subsequent task aimed to uncover accuracy issues with the existing prototype. As it turned out, it became somewhat addressed in the previous task. The emerging value of this question that I had not anticipated though, turned out to be that it verified the accuracy issue as an area that was not limited to just the smaller areas of the body and rather affected the entire mannequin in general.

The last question was put in place in order to observe how the users decided to remove multiple input. Would they continuously press “undo last” until all input was erased, remove all markings and manually center the mannequin or would they use the “reset model” button in order to erase and reset all input with one click?

After the planned questions and tasks were finished, situational follow-up questions were asked in order to clarify different issues or lack thereof earlier in the process. This was to add context in areas where their chosen interaction or input doubt was not clear from both actions and think-aloud.

After performing the general User Experience Research I chose to keep the questions unchanged for the Accessibility Research as I had to see if there were more or less issues, maybe even common ground between all participants in how they made use of the prototype.
The questions I developed for this outlining phase ended up providing me with an immense amount of high quality feedback I was able to make use of in my analysis and subsequently add to my design suggestions for upcoming iterations.

Accomplished research 2016

As mentioned earlier, there were initial issues with the User Research part of my information gathering process. General UX testing went fine as I elected to employ the tried and true Guerrilla testing method *(Klein, 2013)* in order to quickly and efficiently gathering User Satisfaction data and test out the prototype's User Journey in its entirety. After getting a good sense of User Pain Points I needed to verify fringe User Pain Points as well. This affected my next month and a half as I fruitlessly contacted a broad array of organizations and institutions in the hopes of having someone to collaborate with throughout the rest of the process as well as a more varied selection of possible fringe Users. Even with assistance from my Thesis supervisor and other professors from my faculty I failed to establish any form of rapport or relationship with any of the prospective organizations or institutions. An unreasonable amount of time was spent on my part on this effort and my research gathering and consecutive re-design suffered as a result.
All these factors culminated in me seeing no other way of getting my research done other than conducting the same type of Guerrilla testing on a more or less representative group of fringe Users that fit the target audience of the PainDroid application. I sought out various homes for the elderly during low-activity hours and was granted permission to keep them company while asking questions and conducting User Tests with whoever felt like helping me out.
This approach proved to be highly effective as far as feedback goes. There are however several problems with this method of research gathering (albeit I was more or less forced to undertake it).
The first, most gaping flaw is that my Accessibility Testing at this point in time is only conducted on elderly Users. As far as fringe Users go, this group consists of more or

less every single spectrum of Accessibility considerations. Deteriorated sight, less experience with ICT, shakes and language difficulties as well as the fact that most of the people I interacted with had a sort of chronic pain of one kind or another made these Users in theory perfect.

The problem lies inherently in feedback value and the skewed results from a homogenous group. Areas of improvement as far as functionality and Information Architecture can be addressed by testing for the elderly, but my preliminary Accessibility Research is unfortunately not diverse enough to draw any coherent conclusions about shortcomings. On paper the elderly is the perfect group to test on in pursuit of a "one size fits all" approach, but the sheer technological inexperience led to most of the test participants to be afraid of messing up or becoming frustrated with themselves for not understanding this "fancy new technology" as one of the participants described it.

This can also be viewed as a positive though. By addressing the issues of interaction fright and making sure that the users are not afraid of breaking things or messing up I can provide all users with immense contentment and pleasure in their interaction. Testing and designing for Users with little to no experience will nevertheless contribute to "bridging the gap" as designing for that type of fringe User with additional interaction disabilities will contribute value to the accessibility of the product as a whole. A Mozilla Interaction Designer ended up extensively observing a user with non-existent ICT experience due to his realization that this is something that is not often considered in today's society. (https://jboriss.wordpress.com/2011/07/06/user-testing-in-the-wild-joes-first-computer-encounter/) (14.11.2016). These are just justification to provide my research this semester with a semblance of legitimacy I can stand behind. I do, however stand by the fact that it provided good value in its own way.

Test results, analysis and suggested improvements 2016

PainDroid, as it stood at this point in the development process needed a lot of functional work done in addition to extensive design re-works. Several users remarked on the potential of this technology and the prototype should be treated as such. A potentially great system. Further trials directed specifically against users with

interaction disabilities like blindness was needed at this point in order to determine the exact user stories for this sort of user.
The main issues that needs to be sorted out before the project can establish best practice guidelines is first and foremost the rotational attributes of the mannequin. The existing interaction model was completely eviscerated in the preliminary UX test due to its unreliable nature as well as the fact that even the smallest angling of the device would rotate the mannequin. A profound source of frustration and annoyance for the users as well as being a function that is not even noticed if a user prefers to leave their device on a surface while interacting with it.
These are the main factors contributing to the decision to find other ways of rotating the mannequin. Angling your phone does not account for situational disabilities either as you need a good sense of equilibrium and maintain this while interacting with your device. A third contributing factor is the multimodal perspective.
As gyroscopic interaction translates poorly to more stationary devices like computers and TVs the solution implemented for this function needs to be one that intuitively translates into other interaction models and devices. A multimodal perspective should be maintained through any design or development process as the market is constantly undergoing changes as to how a user is able to interact with their respective device *(Neto, Campos), (2014)*.

The second issue that needs to be addressed is the precision of area location on the mannequin. Not confined to only being a pain point for users, the lack of precision affects the general user satisfaction as well as breaking down the trust between user and device. A clearer, more intuitive compartmentalization of the body needs to be implemented in order to ensure a smooth User Interaction Model from start to finish without the user thinking they are addressing the wrong area of their body.

At this point there is a need for a better User Feedback system to be in place in order to ensure the user that they are in fact interacting with the product in a correct manner. This is in some ways implemented by reactions in the mannequin based on input, with colors or movement. However, users seemed put off by the lack of feeling successful in their endeavors to complete a task and required guidance in order to realize that they had in fact reached the end of their journey. There are several ways to implement this. Either by a continuous “save” notification that pops up periodically to show that the User Action has been registered and saved. This might lead to User Frustration however, as wrong input might be saved without actually being ever intended for storing. The most prudent solution (pending testing) is a save button that allows the User to end their own journey on their own terms.

The increase in color intensity in order to define stronger sensations of pain is at this point a hit and miss feature where some users intuitively understand how it works while others are not even aware of its existence. A solution to this might be a dialogue box that allows the user to input the degree of pain AFTER specifying area. This gives increased User Feedback while circumventing the contrast problem that inherently lies in the more transparent colors used to signify lesser degrees of pain in the existing prototype.

The Accessibility tests showed one thing clearly; the need for a proper language selector in order to include people with no knowledge or limited knowledge of languages outside their mother tongue. By adding a functionality that allows the user to select their preferred language, the instances of frustration will lessen as the language barrier is turned into a non-factor.

An issue I had not considered that became apparent both through regular User Testing and Accessibility Research was the need that some female users had for a female mannequin they could interact with. This was addressed both as a familiarity issue, a comfort issue and (as a quite offended individual remarked) an equality issue. *(Photiadis, Zaphiris), (2014)* Address this after exhaustively examining different research papers done in HCI, psychology and User Experience. The researchers theorize that the ability to customize an avatar or a character in an interactive product will increase ownership and affiliation with the product and its core function. This also leads to a greater forming of habitual interaction and increases the user’s experience with, and knowledge of, the product. This also relates to *(Zhang et. al.), (2016)* and their research concerning User Acceptance. A personalized avatar or mannequin (within reasonable limitation) will theoretically improve the user's’ initial response to the prototype and thus lower their frustration in meeting interaction difficulties.

There’s no inherent need for extensive customization of avatar or in this case mannequin appearance outside of the physical gender in the case of this particular application, but if a change of this nature were to increase habitual interaction it would be a welcome addition.

A lot of the fringe Users stated that they would have liked to have individual limbs selected and then interact with a larger representation of said limb in order to increase accuracy. They had several problems with interacting with the mannequin as a whole and stated that it would be easier to select a body part and then be able to interact with that body part specifically. This need was accentuated when the fringe users had to interact with the extremities of the mannequin as they quickly got “lost” while trying to zoom in. This leads to a shared pain point between both fringe users and general users: There’s no collision detection on the 3D object. *(Andrade, Trindade, Silva, Raposo, Barbosa), (2011)* Proved that in the case of 3D objects there will in some cases arise situations where the user zooms in too far and gets stuck inside the object or to some degree feels disoriented by this. By setting up a max zoom element in the program, this can be addressed rather efficiently.

A lot of the issues that were addressed by the users in both tests can be fixed by allowing the users to go in and tweak their app to suit their specific needs. In order to meet this need from the users there might be a need for an extensive options menu that allows the users to tailor their interaction with the app. This will empower the User to specify which language they wish for, the aesthetics of the mannequin, zoom and rotation sensitivity and much more. Blizzard Entertainment received praise from user “Zak552” stated in a Reddit post (https://www.reddit.com/r/Overwatch/comments/4kwjfe/thank_you_blizzard_for_allowing_me_to_snipe_for/) (14.11.2016) that *“...because of your extensive options I am able to play every character in the roster and it feels great. Because of you I made my first snipe in a video game today.”* This shows the need to allow fringe users to tweak and customize their interaction with products in order to find the perfect solution for them individually. *(Andrade, Trindade, Silva, Saposo, Barbosa), (2011)* Also notes in their research the need for user customization. Through the user testing conducted in their research, the researchers found out that the users with little to no experience benefited heavily from various grades of restriction as far as interaction customization went. There were certain areas where the users wished for customization; like scrolling speed and other non-critical functions. These were areas where the users did not fear “messing up” as they rather tailored the speed of transition and scrolling rather than field of view and camera focus.

The experienced users proved to prefer having the ability to be able to customize their entire interaction process in order to freely choose what to automate and not.

Striving for a one size fits all approach will often result in certain areas being less than ideal for every single user no matter how Accessible the product is. By adding a high degree of User Empowerment the overall satisfaction and Accessibility will theoretically increase drastically.

Notes on test subjects

The test subjects in the preliminary UX test were a varied group of users between the ages of 18 up to people in their 40's and 50's. As previously stated this allowed for a solid platform to establish my assumptions and hypotheses going forward. Completely within the bounds of guerrilla testing and the varied prospective user base of PainDroid as a solution, it provided the best possible baseline for further research and investigatory testing.

The follow up testing in regards to interaction disabilities ended up being tested solely on the elderly as previously stated due to time constraint and lacking response from possible collaboration partners and organizations. This approach will skew the test results somewhat and should be considered a weighing argument against the complete validity of the issues and challenges that the conducted tests were able to uncover. The biggest issue concerning the value of the conducted research is due to the enormous unknown factor that testing exclusively on users with a low degree of digital experience provides. Interaction barriers will inevitably be different from elderly users with little to no experience with digital tools and touch devices in particular when compared to users with disabilities who inhabit a higher degree of digital experience.

On the other hand, experience oriented disabilities are interaction barriers that should be considered when working with products that are not widely used at the time of release. Considering all this while going forward, the value of the preliminary research and testing is highly disputable due to the skewed range of users that participated in the tests. Nevertheless, the value could also be considered greater seeing as the research also accounts for experience oriented interaction disabilities. Future researchers should keep this in mind when analyzing this paper and how it does not necessarily apply in a more generalized setting.

2016 summary

After going through the test data and subsequent analysis on the verge of the 2016 fall semester there has been a considerable amount of possible guidelines and directions that could be recommended for future works. The necessity of user empowerment such as allowing the users to manipulate their own interaction model in accordance with their own assessment seems to be one of the main takeaways. To which degree this should be done remained to be seen at this point, although further research and testing is assumed to further investigate and conclude on this point.

There are similarities between two dimensional and three dimensional design, although the importance of these similarities might vary in regards to the way they should be prioritized. For instance the necessity for proper labeling and general information architecture is an almost given in the field of User Experience Design as well as in Universal Design, but has to take secondary priority to the cognitive load of three dimensional solutions. The reason for this is due to the dynamic nature and deep functionality of these programs that bypass a lot of the traditional step by step architectural considerations that one would usually have to make when developing “flat” interfaces.

Research and Testing, 2017

Thanks to my preliminary research and outlining of the main issues facing the "genre" of 3D centered user interfaces I was able to formulate a set of hypotheses in order to further investigate the underlying challenges facing future designers and developers.

Hypotheses

Before delving into the last of my testing, three main hypotheses had to be developed in order to precisely triangulate theoretical best practices, guidelines and possibilities of 3D centered user interfaces as a genre. Building on my preliminary testing, these three hypotheses would present a strong base for me to formulate my own theories and provide my own value to this endeavor.

"True" accessibility of 3D interfaces is extremely difficult or impossible to achieve.

Based on preliminary testing, probing and outlining of the accessibility issues facing the PainDroid prototype there was an overwhelming consensus in the user group. The fact of the matter was that several of the testers without prompting asked if there was any other way of filling in the information. Not just limited to the users with various interaction ability, but also by a few of the users without any of these issues. The reasons behind this were varied. The task of moving the mannequin, defining pain and area was construed as clunky and not precise enough. Several of the users with disabilities (albeit these were all elderly) stated that they would prefer not to struggle with the mannequin and rather have a segmented text-based path to completion. Based on this feedback several fixes and modifications have been put in place in order to ascertain if this feedback is solely due to a lack in the design or if a fair amount of users would like a different interaction model.

I had to conduct user testing on users with deteriorated eye-sight or full on blindness. This user group was the last piece of the puzzle in order to develop a significant theory on three-dimensional User Interfaces and how they measure up to today's accessibility standards.

Due to the adjustments and minor additions and re-design of the prototype (web-based hi-fi prototype) most of the issues with cognitivity, physical interaction disabilities, frustrations and feedback should be addressed.

Hypothesis notwithstanding, I believe that the accessibility aspects of 3D interfaces are not impossible to achieve. There needs to be a valid case to build this faith on, as true accessibility is something that is achieved without special consideration taken to accommodate a set part of the user base. One solution should fit all. There is still a way to salvage "true" accessibility in this case as easily available interaction alternatives still resides in the realm of one solution. By presenting the user with various interaction modes to be selected at their behest is not something that necessarily takes away from this prospect.

In order to ensure accessible interaction for programs that mainly make use of 3D UI there needs to be alternative interaction models and options for the user to tailor their own interaction experience.

This is in some ways connected to the previous hypothesis, although not fully connected. As previously stated, a fully accessible solution and approach should be applied in order to ensure full inclusion and closing of the gap. If my conducted research ends up proving that this is unnecessarily difficult or impossible to develop, there needs to be certain solutions in place that does not pander to a certain group or makes them feel like part of a "special" consideration.

The proposed hypothesis is that by empowering the user to make their own choices in regards to how they want to interact with the mannequin or by removing the 3D figure altogether, they will feel comfortable and familiar with their personal customized interaction mode. Proposed solutions will be tested and accounted for in order to make completely sure if this is to be considered necessary or not. A compartmentalized view of the mannequin can be presented, where the user pre-selects the area they need to define, or a full text-based solution that safe enables screen readers and similar products.

Depending on the outcome of the previous mentioned tests, I will have to develop corresponding alternative solutions with the uncovered information. From there I need to test each interaction mode individually and against each other in order to ascertain which one should be implemented, if none of them should be implemented or if all of them should be implemented wholesale.

Un-cluttering the main UI increases cognitive browsing coupled with explanatory text.

Last semester one of the main uncovered issues of the existing prototype in its current form was the enormous amount of information presented to the user at first glance and interaction. The sheer number of buttons and interactive possibilities made most of the users unsure of how to act and go forward with their task in order to finalize the assignment they set out to complete.
By removing a lot of the options for immediate interaction and grouping them or relocating them in a more cognitively intuitive fashion I hypothesize that most of these issues will be met. In addition to this, a constant feedback of non-intrusive text would theoretically supply the user with the guidance and confirmation they would need to be sure that they are on the right track in order to successfully finish a task.
A clickable prototype has been developed where each of these issues have been addressed on a preliminary level in order to sufficiently validate this hypothesis and set a well-founded academic precedence for this sort of User Interface.
What sets 3D interfaces apart from the more traditional ones is the absolute need to reduce cluttering and increase intuitive linking between the “set” functionalities and the more fluid functionalities of 3D objects on screens.

This theory requires testing on both users with interaction difficulties and core users. In order to fully validate this theory in relation to 3D interfaces my findings should also be seen in relation to known research on general User Experience and Accessibility testing. Even though the aforementioned interaction principles carry over between 2D and 3D there are subtle differences that requires validation and proofing in order to draw out a more concise theory that highlights and proves these differences. This will possibly lessen the difference between development of 2D solutions and 3D solutions and rather provide academic and practical value to both fields individually and collectively.

Research results

Due to my preliminary research predating specific hypotheses and subsequent testing of said hypotheses I have been able to uncover clear and concise issues and guidelines in relation to development and design of three dimensional interfaces. The following section will be split up in hypotheses results, applied prototype changes and user response to changes. This will again be followed by a section describing the value of my research in the form of general suggestions for best practice accessibility considerations when designing three dimensional solutions as well as theorizing how to apply this knowledge in a cross platform perspective.

Hypotheses results

“True” accessibility of 3D interfaces is extremely difficult or impossible to achieve.

Conducted testing resulted in this hypothesis being more of a discussion topic rather than verified or refuted. A “one size” solution is still possible in the sense that if handled correctly, there would be no need for an additional options screen or user specified adaption to the User Interface. Test subjects were positive to adding additional interaction options to the prototype if it allowed them to freely switch between modes in order to accommodate their needs in the moment they would be using their app.

For blind users, the preliminary text based interaction was met with both positive responses and negative responses. The users surmised that they would use too much time registering pain points in the app, even after getting accustomed to the layout. A professed static figure they could interact with was deemed a better solution given that the user could get accustomed to the layout and position of the limbs in question.

The testers with blindness asked about the possibility of search functions in order to search for a specific body part, selecting it and then specifying type of pain and degree of discomfort.

In conclusion: This particular hypothesis can neither be construed as validated or debunked as the phrase itself is not specific enough. As it stands today the tests could be interpreted in such a way that it is not feasible to attain a three dimensional solution that will be accessible to all users with just one type of interaction model available.
Thus it turns into a question of how the program can be designed and developed in such a way that it can offer the users a chance to sufficiently and easily change between interaction modes in correspondence with their needs. This is definitely a possibility given the freedom designers and programmers get when working with such a particularly malleable genre of technology. One size can fit all, but there should be variants of it available to be employed at the users' behest. I will elaborate further on this in my "future work" section.

In order to ensure accessible interaction for programs that mainly make use of 3D UI there needs to be alternative interaction models and options for the user to tailor their own interaction experience.

As the previous hypothesis showed, the need users have to be able to satisfyingly manipulate their own interaction on their own accord is shown to be of utmost importance when considering three dimensional solutions.
The dynamic properties of a three dimensional program makes it extremely powerful regarding functionality and ability to project complex information to the user. This is also where most accessibility issues arise concerning motoric, visual, situational and experience related disabilities come into play. All users with any of the disabilities mentioned above will have varying barriers hindering or stopping them from making full use of the program. In the worst case scenario, they will not be able to access three dimensional programs whatsoever. The users with blindness that participated in the tests stated that they are inherently suspicious to all programs they are unfamiliar with as they cannot visually assess any of the available information or interaction for themselves. They have to trust the information relayed through text-to-voice and are careful whenever presented with a new solution due to this.
This is not something that can be fixed by accessible design or User Experience alone, but the core of this is that if a program fails to at least meet the user's minimum demand of interaction accessibility, they will stop using it.

Thus the alternative interaction modules have to come into play. No matter the vision of any program, if it cannot fulfill its designated role it will be a failed product at a function level. In PainDroid's case this means allowing the user to quickly and efficiently state their pain or discomfort. In order to achieve this there needs to be a set of alternatives available for the users to choose depending on their judgement and need.

It's not a conclusive result though. There might be solutions that can disregard the results of this research and have only one interaction mode available to the user and still be accessible to all. It is not however something that can be obtained by a solution with PainDroid's function and mission at this time. There are possibilities that I have not been able to test or verify such as voice based interaction apps and the like which would enable users to simply tell their device what to do and I will thus have to apply my test results on a purely solution based level.

For programs, on an inherent in-solution basis, there needs to be several interaction modes available for the users that based on testing and research will accommodate motoric, visual, situational and experience related disabilities.

Un-cluttering the main UI increases cognitive browsing coupled with explanatory text.

Almost a given in traditional two dimensional UI design, clearing up space and making sure that labels, descriptions and explanatory texts eases wayfinding for the user. Testing revealed that there is an even greater need for this principle to be maintained in three dimensional design and development due to the unfamiliar way of presenting the user with information. The dynamic object that is the center of the solution is also something to be considered in this regard. The three dimensional object itself requires the user's undivided attention and should only be diverted when the user needs to further manipulate the object in other ways than markup and interaction.

The more I cleaned up the User Interface and the less interactive options the user had available the easier it was for them to feel comfortable and adventurous if you will in their interaction journey. The labeling and positioning of the interactive elements also play a large role in this as there is still a significant need for manipulation and specification in order for the user to sufficiently make use of the product. Supplementary explanatory text was noted as a positive by all users at all points during testing and is something to keep in mind for future designers and developers. The positioning of said supplementary text will depend on testing and research in order to figure out the best solutions for placement and conveying of information. As such there is no definitive guideline that have been uncovered in this regard other than the specific need for this functionality to be implemented.

Prototype changes

Since the preliminary testing and research phase conducted in early spring 2016, the prototype has undergone a multitude of changes and adjustments in accordance with feedback and uncovered user preferences. The first test, conducted in order to uncover the more general problems and issues users would face when interacting with three dimensional interfaces, employed the PainDroid prototype as is while subsequent tests were conducted with iteratively developed HTML/JavaScript prototypes.

The prototype was specifically developed to test the surrounding issues with three dimensional interface interaction rather than the properties of the three dimensional object. The reason for this was both time and resource constraints as well as the fact that apart from how the three dimensional object could be manipulated the users did not remark upon the object itself in any noticeable way.

The main issues uncovered centered around cognitive load, confusing interfaces and sub-par guidance and information architecture while the three dimensional object apart from a few interactive pain points was remarked upon as more or less satisfactory. The pain points that users remarked in regards to the three dimensional object has been addressed both through supporting literature in a UX sense *(Andrade, Trindade, Silva, Raposo, Barbosa), (2011)* and user feedback uncovered during testing.

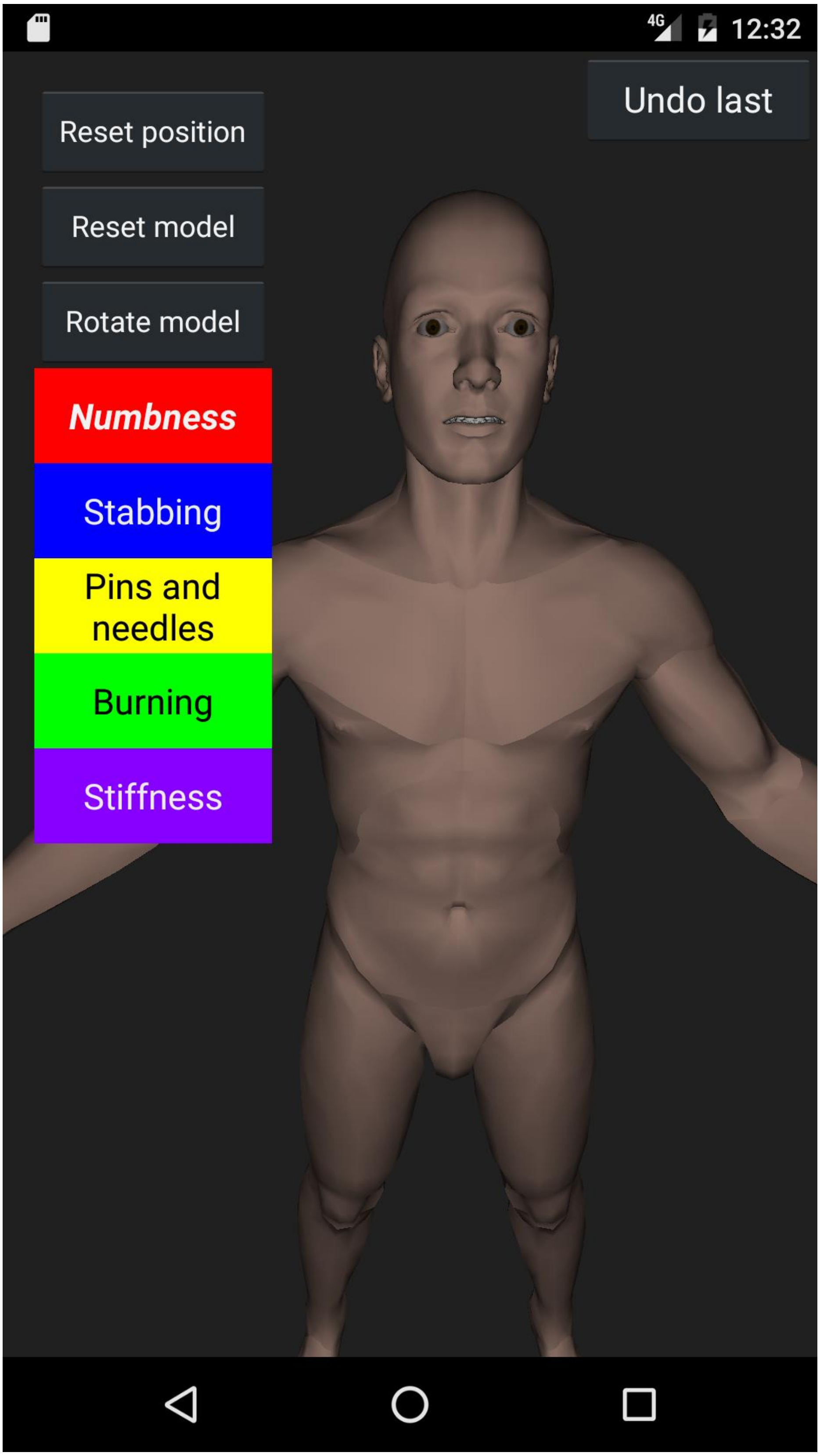

Figure 4: The PainDroid app as it stands today.

The most pressing issues facing this project in regards to finding ways of making three dimensional interfaces accessible were largely dependent on the functions and issues presented alongside the object rather than the object itself.
This leads to an interesting question: Are human users better able to cognitively grasp digital three dimensional objects (or the illusion thereof) than flat two dimensional point and click solutions? This will be elaborated on in further works, and may warrant its own paper.
The first objective of the solution prototyping was to clear out the cluttering of the interface in order to place the mannequin object sufficiently in the center.
As the conducted research, observations and test shows there are several issues that were found in the existing prototype which all have multi-faceted possible methods of approach. The main issue uncovered in analysis was the amount of screen clutter and the perceived lack of intuitive continuation for the user's story as seen from a first-time user perspective. On opening the application, the User is confronted with three dark grey functionality buttons with more or less the same color (#262B2F on #202020) that does not conform to AA standard for color contrast. Contrast fixes will be applied before testing preliminary designs, at this point the main focus was on fixing the main layout issues and architectural shortcomings of the prototype. With a button in the upper left corner with the same color contrast as the functionality buttons as an additional option, these buttons were shown to be given less attention than the five brightly colored pain sensation specifier buttons. The five pain sensation specification buttons are not designed in the same way as the previously mentioned functionality buttons and may not be considered interactive functionality even though they are the main eye catchers. All these buttons and functions make a grand total of nine different interactive input areas all put in close proximity to the mannequin disregarding the actual purpose of the buttons in relation to the functionality inherent in them.
This current solution did in several cases lead to a higher rate of user frustration than anticipated. The lack of conformity between the mannequin functionality buttons and the pain sensation specification buttons lead the users to doubt what parts of the interface were interactive and which were not. Add to this the fact that there exists a very minor degree of user feedback signifying which pain sensation they have currently chosen to activate (the activated sensation specification in the above picture is “numbness”, proven by the label entering a cursive font) and both general

users and fringe users felt quite lost. This is a bad first impression of the application at this point in time and will have to be addressed.

As far as the information architecture and positioning of the interactive buttons go, the buttons that directly relate to moving, rotating and resetting the mannequin as well as removing input is positioned in a non-relatable position to the actual actions the user input would engage.

By positioning all functionality to the left of the mannequin, a displaced sense of intuitive relation takes hold on the user and enables a sense of doubt as to where their input would be applied to the prototype. The labeling that have been put in place on the buttons is addressing this issue in some way, but does in the end force the user to have to read and understand the label before interacting with it in order to be sure of what the button does. Relocating mannequin related functionality buttons will go a long way in erasing this issue. In order to ease the amount of information presented to the user at initial first time contact there is a definitive need to reduce the amount of possible clickables. The pain sensation significators can be compressed into a selector menu in order to clear up space.

Figure 5: A preliminary interaction design based off of user feedback. Screenshot from web-based semi-interactive prototype.

The core idea of this redesign is to clear out clutter and relocate functionality in order to clear out screen clutter and allocate elements to a more intuitive grouping.
The “type of pain” element will open a roll-down menu on click that allows the User to choose which of the sensations they are experiencing. An indicator above or around the mannequin will be present at later stages, but needs further testing before being implemented into the functional prototype. As the test analysis showed us that one of the main issues with the initial user response is due to the fact that the User feels overwhelmed by the sheer amount of information and interaction made available to them. By making sure that the types of pain sensation indicators are not present in the interface at all times, screen clutter and information overload will most likely be

reduced a significant amount. The button itself is larger and placed in the top left corner of the screen in order to increase visibility and the chance that the user notices during their first initial observation.

The previously conducted User Research proved that there was a specific need to include User Feedback as to whether or not their story had reached completion. By adding an old-fashioned mandatory save button the theory is that the User will decide when they feel their interaction to be completed as well as when and what they decide to report. This in turn removes any doubt the User might have had of having their input saved or discarded.

The biggest pain point for the users during the User Research phase collectively was proven to be the rotational input methods of the prototype. There were instances of immense levels of frustration and even in some cases outright anger and despair. The gyroscopic rotation had to be cut in favor of alternative interaction paths, but how would this be implemented with as much efficiency and intuitive layout as possible? The first part of the pain point that most users noted was as my analysis show the gyroscope. Every single user in every single interaction test tried to swipe sideways in order to rotate the mannequin as an intuitive extension of the fact that in order to zoom and move the figure up and down you would have to make use of your fingers in a pinching motion for zoom or an up and down motion for moving the mannequin up and down. Due to this, the idea is that seeing as the cognitively correct solution is to rotate by finger swiping left or right we enable the users to do just this. This takes away the less accurate and immensely more frustrating gyroscopic element and makes sure that the interactive components make more sense from an interactive perspective. A lot of the fringe users and some of the middle users chose to make use of the “rotate” button during the conducted tests and research. The main issue with this approach, as it was uncovered, was that it only rotated the mannequin clockwise without allowing the user to keep the button pressed for rapid rotation and due to this needed to incessantly tap the button in order to get where they wished to go. In order to address this as well as trying to achieve a cleaner, more intuitive interface the decision was made to move this functionality directly under the mannequin and to each rotational direction’s respective sides. This would allow the users to make their choice as to which direction the mannequin should rotate as well as freeing up space around the figure itself in order to decrease (as mentioned before) the chance of information overload for the users. These buttons have to allow for rotation while pressed down, of course and not just on tap as this proved to be a very apparent nuisance to the users doing the test and research phase.

In order to complete the initial endeavor to reduce clutter and chance of information overload the “reset” and “remove previous” elements were moved down between the rotational elements and reduced to two buttons rather than the original three. The button to reset will perform a hard reset and all markups as well as the mannequin’s position as far as rotation and zoom goes. The “clear markers” will remove all markup input and clear out the mannequin for all markings made in the User’s current session.

The way the users register their sense of pain or discomfort will undergo a few design changes as well. After selecting the desired sensation and area on the body for location, a dialogue box will appear where the users can declare their rating of said sensation. This functionality adds to the degree of feedback given to the users as well as showing them that there are ways to rate their sensation of pain in the program. This functionality was not always apparent to them during the test and research phase and had to be addressed or removed. Due to this particular research focusing on the patient and not the health professional that would interact with the product, the rating system was kept in place. It will be a consideration at a later stage for when someone would like to account for the e-health aspect of the prototype rather than the Universal Design or Usability aspect of it.

The need for alternative modes of interaction

Some fringe users had difficulty interacting with the 3D model at a basic level and wondered if there were any other alternative ways of logging their discomfort or sensations of pain.
Theoretically an alternative interaction model can be employed both for users who feel more comfortable with text-based interaction as well as making it easier to make the application accessible to blind users. By compartmentalizing this alternative interface into sub-groups representing each body part, then area of said part there will be a more accessible step by step procedure for whichever User feels more comfortable with text-based input rather than interacting with a 3D model. This also relates to the previously mentioned user empowerment by once again allowing the user to tailor their user story to their particular needs.

Image 6: preliminary design of text-based interaction for users who wish for it as well as making it easier to enable usage by people suffering from vision impairment

If text based interaction is selected by the user, they will be redirected to a menu organized in accordance with regular body structure where the head, neck and torso is followed by the body's extremities. Based on the chosen user input another dialogue will open to allow the user to further specify the area of the sensation of pain in order to narrow it down further. This in turn opens the section that allows the user to choose their area of felt discomfort. After selecting their correct area of pain or discomfort the user will accept their user story by submitting their data with the save button that appears after selecting. All steps can be backtracked or canceled at the point of selection in order to allow the user complete freedom of movement.

The colors are high contrast in accordance with the standardized guidelines for accessibility *(ISO/IEC 24751-1:2008 (and related subgroups))* and the works of *(Chen, Savage, Chourasia, Wiegmann, Sesto), (2014)*. The aforementioned paper includes conducted tests on a grand total of 53 participants, one control group of 15 users without motor control disabilities and 38 participants with motor control disabilities. The age and gender distribution was similar between groups in order to get the most viable results. The method employed for statistical contextualization was in the form of two questionnaires. The first questionnaire was conducted in order to determine the statistics concerning age, diagnosis, how long the users had been living with the diagnosis, living arrangements as well as questions about each participant's experience with day to day technology use.

For design evaluation the researchers conducted user experience testing in a completion time/interaction accuracy testing context to map out the ideal button sizes. The ideal sizes were measured up against button tap misses (defined as a touch that landed outside of the intended area), error ratings (defined as a touch which resulted in activating the wrong button) and completion timing (measured in trials that had no "miss" or "error" interactions).

The gathered data from the testing group and the control group was then measured in order to draw contextual coherences between the testing data.

Their tests and research clearly showed the need for larger button sizes as well as a certain amount of room between each interactive element. This has been taken to heart and into consideration when developing the text based interaction prototype.

By allowing the user to switch to this mode at will they can freely select their method of interaction in accordance with their needs and specification as a user. This falls in line with the previous point of user empowerment and how it will increase user satisfaction and attachment. A point that should not be foregone is also how this particular interaction module makes it easier for users suffering from sight deterioration and or blindness to have a mode that enables screen reader functionality.

It being considered somewhat tricky to make a fluidly moving avatar available for screen reader functionality as well as enabling users with lesser sight or blindness, the text based interaction interface will make incorporating the much needed screen reader a problem that is easily solved.

At later stages in the process, a third interaction mode was presented. This mode would not be text based or a dynamic three dimensional model, but rather a static three dimensional model that could exist in four states at the user's behest. By keeping the mannequin in a static position on a set area of the screen, users with deteriorated eyesight stated that they would most likely be able to use PainDroid faster than through a step by step triangulation solution. There were however some disagreeing observations in this regard that pushed the development in the direction of ending up with three alternatives that would be presented to the user to accommodate each user's individual interaction need. Thus the prototype needed a non-intrusive, non-disturbing interaction alternative that would prompt the user to understand their freedom to jump between interaction modes. The choice fell on adding a button below the pain selector as it would be within effortless view for the user and thus require a minimum amount of cognitive effort to understand the underlying functionality as well as finding it in the interface.

This particular part of the functionality is added based on assumptions and the need to have an implemented selector to freely switch between modes. For the actual usability or user experience of this last piece of functionality subsequent user testing or A/B testing is deemed necessary to conclusively decide how to sufficiently solve the placement and design of the interaction mode selector.

Figure 6: Final prototype sketch showcasing the idea behind the design of the Ground User Interface

Alternative interaction methods deemed unfit for further research

Gestural interfaces: As *(Brock, Truillet, Oriola and Jouffraiis), (2014)* found out in their research to find out if gestural interaction might elevate the user friendliness and experience, gestural interaction is not a reliable method of replacing capacitive touch screens at this point in time. The paper highlights the issues users with visual impairments face when interacting with touch screens: The biggest difference between touch screens and regular tactile interaction is that there is little consequential feedback as to WHAT you are touching on the screen and where to go for the next action. Furthermore, the fact that there interface is subject to change makes it difficult to remember objective completion, as well as making visually impaired users almost afraid of accidentally activating functions that they do not wish to activate. The paper does not, however account for the presence of audio feedback to the user. With the above-mentioned preliminary design for blind user enabling in place, a structure and architecture is put in place that will allow for easier incorporation of audio feedback. If you see all these factors together as a whole piece of information, there is little to no need to pursue an alternative interaction method that seeks to employ gesture based user interaction. The scrolling of the 3D mannequin was proven throughout the test and research phase as one of the main pain point localizations and would in the worst case scenario be even more problematic for the user if gestural interaction is implemented on top of this.

The paper itself also goes to conclude that gestural interaction on handheld devices is a subject and a technology that still leaves a lot to be desired. At this point in time considering the fact that the application prototype PainDroid itself is operating on decently new ground as far as interface design and accessibility goes, there seems to be no reason to make the project more advanced and convoluted than it already is. Thus gestural interaction has been deemed as an interaction model that cannot be investigated upon further for this research project.

Text based input: Differing from the text based navigation design and prototype, text based input would be an interaction model that would allow the user to write in their sensation of pain or discomfort in order to report. This type of interaction might mimic the oral account patients would give to their doctor or other medical personnel in similar situations, but would demand a lot of knowledge and an exorbitant amount of additional clicks on the user’s side. In order to properly allow for this type of user input the prototype would have to inhibit a large thesaurus that meets the user’s language and knowledge- or lack thereof of the specific body parts they want to register.

Text based input is at this point deemed a time consuming, unnecessarily convoluted interaction model that take up an uncalled for amount of time on the user’s time and energy in order to use correctly. Text based information input is therefore deemed not effective enough to warrant further research.

Ownership by user personalization: The need for user empowerment and user personification has come up earlier in this paper, but within the confines of

functionality and alternative input and registration methods. It has also been deemed as a low priority necessity to include the option to determine the gender specification of the mannequin by the user. Both of these already addressed considerations have been in order to increase User Acceptance and Accessibility by tailoring their interaction experience to each user's specific needs and if applicable, disabilities.
User personalization, on the other hand, is a design method enacted upon in order to increase habitual use of a product. By allowing the user to customize their mannequin or in this case Avatar one could argue that they would feel a greater sense of ownership and attachment to the application thus prompting more frequent use and lower instances of frustration. *(Photiadis, Zaphiris), (2014)* elaborates on this point in their research on avatar design where the users were allowed to make personalized digital versions of themselves. The researchers theorized that the ability to customize an avatar or a character in an interactive product will increase ownership and affiliation with the product and its core function. This also leads to a greater forming of habitual interaction and increases the user's experience with, and knowledge of, the product.
The reason this design approach is deemed not important at this time is due to the fact that the main focus of the research being conducted in relation to PainDroid is multimodal accessibility. Had it been a corporate development project rather than scientifical, there would be well founded reasons to include this in the application. As it stands, however, there is little to no need for extended personalization of PainDroid as there are no stakeholders to appease as well as the fact that it does not provide any valuable insight into Accessible 3D design or multimodal design synonyms.
Avatar customization and personalization is due to this considered unnecessary for this research project going forward.

Future works

There are a multitude of ways one can choose to adjust a three dimensional product due to the varied application areas this technology can be employed. This inherent flexibility and ability to easily accommodate various situations, fields of work and disabilities makes the different accessibility considerations one can employ equally numerous and applicable.

During the interviews, tests and observations that were conducted over the course of this project, the vast amount of possible accessibility implementations uncovered turned out to be quite staggering in their sheer multitude. This last chapter will attempt to recommend the most prudent and attractive accessibility measures that should be elaborated upon and considered going forward with three dimensional interfaces and solutions.

Voice directed interaction is potentially one of the most powerful implementations that can be put in place in these types of solutions. The user speaks and commands, while the subsequent acknowledgement and interaction is shown or told through visual or spoken feedback. This solution does not need to be in-app implemented either, necessarily speaking. Amazon Echo and its assistant Alexa is already making headway into the field of voice guided interfaces and could possibly offer immense power and interaction possibilities to all users regardless of interaction difficulties. In the context of PainDroid, speech based interaction will potentially further accommodate the original goal of the application as joint pains or recurring muscle pains may impede interaction with any sort of device short of speech based interaction. If prudent steps are taken in order to make PainDroid and similar three dimensional products and solutions functional against Echo/Alexa and similar third party products, the time and effort needed to make 3D products accessible will possibly be drastically reduced.

Search functionality in-app is something that was shown to be an attractive addition according to several of the users with eye-related issues. Considering the previous point of introducing functionality that accommodates speech controls, a search function is not that farfetched in PainDroid’s case. Combined with the text based interaction model with its generalized markable areas, a search function would theoretically make another interaction model available to the user. Time constraints

and lack of resources stopped the project from investigating this sufficiently, however.
Setting aside the context of PainDroid for a moment, consideration should be given to a point mentioned earlier during my discussion around hypotheses. Specifically if it's possible to design and develop three dimensional solutions where all users can make use of the same singular interaction mode in the same way we strive to do with traditional two dimensional products? This project was not meant to figure out the answer to this and certainly was only able to elaborate in a contextual sense for the particular product it was conducted under. The question is nevertheless an extremely important one as there is no definitive research done on this. The textbook definition of an accessible/Universally Designed product is that it is one product that meets the requirements of all users. Is this feasible with something as complex and dynamic as three dimensional objects in a two dimensional space? Rather than debating the theory of this statement I would heavily recommend that this is further expanded upon in later research projects as the varied nature of three dimensional solutions and the contexts under which they will be used warrants its own 20 000 word paper.
Finally, the question that could wishfully be concluded in this thesis, but could not be: Are three dimensional interfaces as a solution "genre" better able to convey meaning, weight and cognitive understanding than two dimensional solutions? Are flat, two dimensional digital products the best we can do in a physical world where everything except written information is three dimensional and has its own weight and perceived ability?
The reason I highlight this last is due to the fact that the potential of three dimensional interfaces present massive opportunities to various users in various fields. Complicated interfaces can be simplified into dynamic objects, layered, hard to convey biology, architecture, geography and industry can suddenly be translated into digital products that lowers the bar for professionals in each field digitally speaking and enables them to focus on the body of their work rather than complex and flat corresponding solutions.
Is three dimensional solutions the better approach in all ways, some ways or none? Would all users learn to enable three dimensional solutions faster than existing solutions within the same parameters? The future of Human-Computer Interaction and Accessible Design could get a head start on the ICT industry if conclusive research is done on this in addition to how to best implement them as well as where.

As far as the question of cross platform development goes, the regret of not having sufficient time and resources to conduct satisfactory testing on anything other than desktop computers and handheld devices is significant. At face value there is little difference between a touch based device and a desktop if you allocate interaction techniques in brackets of interaction synonyms. The issue this particular thesis faces is the inability to prove any of the theories concerning cross platform development. There are several short leaps of imagination and theories from uncovered interaction modes, techniques and which synonyms these can be replaced with on different platforms, but the inability to prove any of these would render the proposed solutions imaginative at best. In order to achieve industrial accessibility where the user's preferred platform is no longer an obstacle to actual employment and use.

Due to the varied nature of the devices and extensions available to these, time should be allotted to figuring out accessibility and user experience aspects of products in a cross platform perspective. In this light, several of my research questions setting out were in this context. Even though issues during the research phase force the project to somewhat move away from exhaustively investigate this subject, there was still some significant observations made during testing and research.

The solutions that was enabled during the iterative testing and research phase was a HTML/CSS prototype that allowed for quicker fixes, customizations and retesting than if all the uncovered feedback had to be implemented into the PainDroid app natively. Thanks to this decision, several opportunities for cross referencing use cases between touch devices and desktop computers were possible.

Starting out, this research project had as one of its main research questions "How do you make a 3D interface Universally available cross-platform?"

This was, as previously stated downgraded as a secondary research question and the project never achieved proper time or resource allocation to exhaustively investigate the subject. Even so, the question is an interesting one and it would be remiss of this thesis to not elaborate on the knowledge that was uncovered during the test and research phase.

The question of interaction synonyms stood out and how developers and designers need to figure out how to translate interaction models between two different devices in order to keep the experience coherent. There is a particular need for techniques in the way of figuring out how dynamic digital products should be designed for cross platform use in order to accommodate as many users as possible. This ranges from three dimensional interfaces to maps and various other content that is not only conveying information, but also has a deeper dynamic interface which requires a wider range of input in order to function at its intended level.

Discussion

Backtracking to the fact that there has been little headway made in this particular subject earlier, discounting the research done on general User Experience in the context of three dimensional interfaces, the conclusions that this thesis is able to draw is up for debate and closer scrutiny by future researchers. As there are not a lot of previous research done on the human computer interaction on three dimensional interfaces there exists little basis to establish the validity of the claims this paper makes without sufficient data to problematize around. Thus the knowledge uncovered here, even if it coincides with knowledge, research and best practices for universal design on traditional two dimensional interfaces cannot be conclusively labeled as a priori knowledge and therefore needs to be validated or disproven as the knowledge of the field expands.

Nevertheless, there are some standout similarities and differences that can be pointed out at this stage. The similarities between two dimensional- and three dimensional interface design are many, much the same way as Universal Design and User Experience Design has similarities with subtle differences.

The same principles apply for 2D and 3D accessibility design in some cases. For example, the issue of color contrasts, clearly defined language, structure, help text, alt text and the rest of the WCAG standardization guidelines apply here as well. The same general principles for accessibility design apply to all digital products, no matter the platform or intended purpose of the product.

The difference lies in how you treat the intended information and functionality behind the interface and the techniques designers and developers have to employ in order to convey this to the user.

In two dimensional interfaces you need a cognitively easy to understand structure, layout and architecture in addition to the standardized guidelines for accessibility. An interface can be accessible and universally designed while being absolutely horrible to use due to confusing layout, labeling or information architecture. Thus the task of finding methods of conveying this information falls to the people behind the product in order to not only make the information and functionality accessible to all, but also to make the experience of finishing the task easy and even enjoyable.

In three dimensional interfaces however, the purpose and inherent functionality of the product needs to be at the forefront in addition to standardized guidelines. Where the structure and architecture of the information and how it's laid out when being presented to the user, three dimensional interfaces need to make all this information understandable from the start in order to prompt the user to interact with the product in the product's intended manner. The function and purpose of three dimensional interfaces needs to be understood almost before the users make their first input while a two dimensional interface can afford to allow the information available at index level explain and guide. Due to the necessity of placing as much screen area and cognitive emphasis on the dynamic object of a three dimensional interface contrary to the conveyed information of a two dimensional interface a three dimensional interface needs to have way bigger rate of affordability and feedback on all levels than a two dimensional interface. Without contradicting the guidelines and best practices that are in place for design and development of two dimensional interfaces and products, the focus and emphasis on three dimensional interfaces is somewhat different regarding what is important in order to ensure an accessible and pleasurable interaction experience.

The results of this particular thesis can be split up in two main categories of value: Value in the academic sense for Universal Design as a research subject and value for the IT industry as far as best practices are concerned.

The value provided for academic circles, while not necessarily contributing leaps and bounds as far as knowledge in the Universal Design field, ensures a solid platform for further endeavors into Universal Design of three dimensional interfaces. As the uncovered knowledge in this thesis uncovers where the focus should lie during design and development rather than figuring out new and exciting ways of ensuring accessibility, the field of Universal Design will gain a solid platform to build upon while further investigating the deeper accessibility aspects of 3D based products. When and where is three dimensional solutions better than two dimensional? Where are they worse? Will a 3D interface help one group more than another? Will it be easier to understand a three dimensional interface or will it maybe feel more exciting, fun and adventurous for users which in turn leads to a higher degree of self-learning and exercise in the use of each particular system? Is the cognitive effort lower? Questions like these can hopefully be answered sooner if founded on the more preliminary knowledge of the genre of three dimensional products than before this thesis was written. For immediate academic value the highlight should be set on the

fact that the differences between traditional 2D based products as opposed to 3D based products are minor, but significant.
For the IT industry in private and public sectors, this thesis will hopefully provide an expanded view of what solutions are the best fit for each individual case. By drawing on the uncovered information of this paper, a more precise analysis of cost and value as to how a specific problem should be solved will hopefully be attainable.
From the research that has been conducted in this paper, a more in depth knowledge of how to make use of three dimensional interfaces in industrial development projects can be obtained, thus aiding companies and teams in finding the best possible solution depending on the problem they are trying to solve.
For interpretation purposes the uncovered knowledge can be viewed as preliminary steps into the intricate accessibility issues surrounding three dimensional technology and cross platform development. As the previously mentioned time constraints and manpower issues resulted in more generalized all round assessment of the techniques, considerations and focus areas one should dedicate the most time and care to in order to achieve accessible three dimensional interfaces on a basic level. The thesis should in no way be considered the final word on this, however, due to the lack of previous work done in this particular area of research. This paper, no matter how much its inherent knowledge contribution is estimated to be, should be interpreted as a good basis for further endeavors into the genre of three dimensional design and development. The issues and difficulties that arose throughout the project should also be taken into consideration as to how much the value of the conducted research could be estimated to be worth. The results are suggested to be viewed as preliminary knowledge of this area of accessibility design and development and be put under further testing and research as such, albeit preferable in combination with other problem statements that would be the main focus.
Secondary focus for future researchers would be suggested to keep in mind the weak points of this study and take care to address these during their own research in order to solidify this particular paper’s findings and further contribute to the basic foundation of universal design principles in a three dimensional product context.
On the subject of weak points, this research paper makes no effort to hide the areas where the conducted tests and results would be considered weak. Although the results provide value (as stated multiple times) they do so under the pretence and understanding that the first push into the breach rarely is a successful one. Multiple

sessions, papers and theses will be needed to solidify, add to or even disprove and change the considerations and best practices uncovered in this paper. Apart from being new and untested, the base that this knowledge is drawn from is somewhat homogenous as far as sample variance is concerned. General usability testing was carried out on just a single user group age-wise which in a scientific research setting provides shaky foundation for certainty of conclusion to be reached. The strong aspect of this research paper can be argued to arise from the same area. Due to the new ways of interacting with a somewhat traditional solution presented in an innovative way, having a group of elderly users with little to no digital experience can be seen as a trial by fire for an emerging interface technology. The data and subsequent analysis will most likely return an over compensation for this technology in order to make it as readily available as possible cognitively speaking. By testing technology that will be varying degrees of unfamiliar to most users on users who are largely unfamiliar with digital technology (by today's standards) the returned data and analysis has provided an approach and conclusion that will aim above and beyond the minimum of how to make the threshold of use as low as possible.

The immediate results of this paper will provide significant value to researchers in the first few years following its completion. Due to the preliminary nature of the uncovered knowledge it can be compared to the first research and findings in digital accessibility. The first step will not necessarily provide tremendous, far reaching and world changing value, but may enable future researchers to take steps beyond just the basic considerations of minimum accessibility as well as combining it with other fields in order to further development.

The findings of this paper should probably be viewed as a general baseline for how developers and designers should work with three dimensional products throughout a development process in order to assuage the pain points and potential issues users will face. Time constraints, research sample issues and the untested grounds for this particular research area were all factors that contributed to making the knowledge that can be extracted from this research paper

Conclusion

At the start of the thesis, the fundamental constant problem and question that were set as guidelines were:
“Improving and expanding upon User Experience and Universal Design considerations for 3D interface program development”. A
“What design considerations should be emphasized in order to ensure the Accessibility of a 3D-based interface?”
To conclude: The rapid increase in hardware capabilities on all devices, both handheld and stationary are making it possible to enable designers and developers to create more and more dynamic and versatile products.
These products might take the shape and abilities of three dimensional interfaces that seek to convey deep, complex information and functionality in a manner that makes all this information and functionality readily available in one screen. This thesis sought to make sense of the demands and expectations that users have when they are presented with such a solution. The context of these demands and expectations were set within the subject of Universal Design and User Experience. With the guiding statement of how one would go about “Improving and expanding upon User Experience and Universal Design considerations for 3D interface program development” this thesis exhaustively investigated how to construe basic best practices and guidelines for future researchers, designers and developers working to build three dimensional interfaces.
Beyond the already established guidelines for interface accessibility, the research conducted in this thesis provided valuable insight into certain key elements. Three dimensional interfaces provide the users with a contextual way of interacting with a digital product that a two dimensional interface is hard pressed to match. This natural understanding springing out of contextual interaction prompted users to dedicate most of their attention towards the dynamic three dimensional object in the middle of the screen. This lead to a ton of frustration where the UI overlapped with the object in cases where the screen was considered cluttered. Thus a three dimensional interface should take care when making the tradeoff between functionality and object when deciding button size, layout and interaction alternatives in the GUI of the product. The object needs to emulate weight and has to behave in a way that the users can foresee and understand even before input is made in some cases.

Collision detection, rotation sensitivity, relocation sensitivity and zoom needs exhaustive testing and tweaking in order to behave in a manner that is easy to comprehend and anticipate.

The stand out discovery during the conducted research and subsequent analysis was for all intents and purposes the realization that under the context of three dimensional interfaces, there needs to be significant trust and faith in the user from the developer's side. Users are not all the same, with a myriad of different backgrounds, interaction difficulties, varying degrees of experience which in turn affects preferred method of interaction etc... This in turn demands the developers and designers to create different modes of interaction or even, in some cases, allow the users to properly customize their own interaction at base levels. Speaking for accessibility and its intents and purposes, there are easier arguments to be made for this than for general User Experience, but the arguments overlap. By allowing the users to freely select modes or (depending on the solution and its inherent intricacy) even presenting them with a feature that allows them to thoroughly customize parts of their interaction or the entire product if necessary.

Three dimensional interfaces and products present an opportunity for researcher, developers and designers to create intricate, beautiful and complex products that cut down time, cost and effort from the users for tasks that previously were overly tiresome, slow or difficult. This potential comes with a high degree of risk concerning missteps. However, with sufficient time allocated to understanding contextual user needs in regards to when, how and why the product will be used, three dimensional interfaces will hopefully elevate digital products to a new plateau of functionality and accessibility in both public and private sectors.

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Appendices

1. Master Thesis code scripts: The source code for the product I was working with from the start as well as the iterative HTML prototype that was deployed in order to validate the shorter and faster theories.
2. A PowerPoint with speaker notes from a presentation done for BEKK consulting on the topic of three dimensional products, the value of this and important things to remember when building one. This is included to showcase thinking employed when considering the value contributed to three dimensional solutions from a private market perspective.
3. Notes, ramblings, thoughts, sketches and scribbles made that contributed to the project in various ways.