Creating interactive custom controller installations to improve a museum exhibition

Bachelor Thesis Creative Technology

Leonardo Chávez Sáenz

Creative Technology
Faculty of Electrical Engineering, Mathematics and Computer Science
University of Twente

Supervisor: Dr. ir. Robby van Delden
Critical observer: Dr. ir. Randy Klaassen

Date: 22/04/2022

Abstract

Museums are constantly evolving as they compete in the leisure market. One of the innovations that can be useful for them is the custom controller installation. This installation provides an interactive experience through unique physical means. In the context of this project, they will be explored with the use of serious games. Games that focus on both education and entertainment. This research aims to firstly explore different forms of literature and existing technologies for the benefits of interactive installations and then sees how this can be applied with serious games.

In the project the goal was to design three installations based on three fitting games. The designs are made in collaboration with a museum and a gaming company which made games for each installation. From the researcher's side, this meant that three different designs had to be ideated and then further refined through different iterations and prototypes. After completing the prototypes, three real custom controller installations were developed that will be placed in a permanent exhibition in the museum. The installations were tested through a playtest to gather both qualitative and quantitative data. The data was processed to create satisfying answers to the research questions and see what benefits can be used for future installations.

The results were three very distinct custom controller installations with unique forms of interaction that helped improve the museum experience in multiple ways. In the future these custom controllers can still be improved upon based on the findings and based on future tests with the target audience. After this research, the development of custom installations will continue in the collaborating museum to create new forms of interactive controllers.

Acknowledgements

In these first words, I want to show a token of appreciation to the people who made this project possible. First, my supervisor Robby van Delden, who continuously helped through discussions, advice and providing interesting ideas and research. Next, my critical observer Randy Klaassen, who, together with Robby, provided guidance and supported me in delivering a satisfying report.

Next, I would like to thank Niels Leenders, Pieter Boom and Grietinus Snaak. These were the clients that worked with me. They were always willing to make time for meetings and constantly provided useful feedback and suggestions for the installations and the evaluation test. Finally, I would like to thank my friends and family who continuously supported me and helped me with different tasks like reviewing the report or building the prototype. Together we created a graduation project that I can proudly present.

Table of contents

Abstract 2

Acknowledgements 3

Table of contents 4

List of Figures 7

List of Tables 8

Chapter 1 - Introduction 9

1.1 Research outline 10

Chapter 2 - Background 12

2.1 Context 12

2.2 The enrichment of the museum engagement 12

2.3 Motivate learning with interactive installations 14

2.4 The benefit of custom controllers vs. traditional controllers 16

2.3 State of the art 17

2.3.1 Available interactive technology 17

2.3.2 Expert Interview with 100%FAT 20

2.3.3 Interactive Museum visits 23

2.4 Preliminary conclusion 25

Chapter 3 - Methods and techniques 27

3.1 Creative Technology Design Process 27

3.2 The Scrum Agile Methodology 28

Chapter 4 - Contextual analysis 30

4.1 Stakeholder analysis 30

4.2 Project-based goals and constraints 31

4.3 Research-based topics of interest 32

Chapter 5 - Ideation 34

5.1 Mind map 34

5.2 Morphological design 34

5.3 Results of the ideation 36

5.3.1 Installation 1: Solar system exploration 36

5.3.2 Installation 2: Sun processes 37
5.3.3 Installation 3: Journey through time; The Sun and the earth 38
Chapter 6 - Specification 40
6.1 3D model concepts 40
6.2 Development of Blueprints 41
6.2.1 Budget plan 42
6.2.2 The hardware and electrical components 42
6.2.3 The frames 43
6.3 Prototyping 45
6.3.1 First iteration prototypes 45
6.3.2 Final iteration prototypes 46
6.3.3 Pitfalls and improvement 47
6.4 Feedback on prototypes 48
Chapter 7 - Realisation 49
7.1 Building of the frames 49
7.2 Integration of electronics 49
7.3 Game integration 51
7.4 Final placement in Cosmos 51
Chapter 8 - Evaluation 53
8.1 Participants 53
8.2 Testing methods 53
8.3 Procedure of the user-test 55
8.5 Results 55
8.5.1 Statistical analyses 56
8.5.2 Observations and remarks 59
Chapter 9 - Discussion 62
The design 62
Problems and limitations 62
Future Work and recommendations 64
Chapter 10 - Conclusion 65
Appendix A: Interview notes 100%FAT 67

Appendix B: Notes museum visit NEMO 69
Appendix C: Notes museum visit Corpus 71
Appendix D: Literature matrix 73
Appendix E: Mind map 76
Appendix F: Morphological design chart 77
Appendix G: Question setup 80
Appendix H: Questionnaire 83
Section 1 83
Section 2 84
Any remarks? 85
References 86
Footnotes 90

List of Figures

Figure 1: A prototype of Globe4D with a projection of the Earth’s continents 168 million years ago (Companje et al., 2006) 16

Figure 2: A simplified diagram of how a typical projection system works (Geller, 2006) 18

Figure 3: Children play with UC Davis' Augmented Reality Sandbox at the 2016 USA Science and Engineering Festival. (Segale, 2016) 19

Figure 4: Zoomviewers at the Brorfelde Observatorium Experience. (100%FAT, n.d.) 20

Figure 5: A user having difficulties interacting with an installation due to the accessibility 23

Figure 6: A Creative Technology Design Process. (Mader & Eggink, 2014) 27

Figure 7: Results of morphological design ideation in self-made sketches 35

Figure 8: Prototype of game 1, made by GameLab Oost 36

Figure 9: Prototype of game 2, made by GameLab Oost 37

Figure 10: Prototype of game 3, made by GameLab Oost 38

Figure 11: Final ideation concepts for each installation 39

Figure 12: Different installation models to compare by Zario Vries 40

Figure 13: My implementation of the final concepts of the installations, rendered in Maya 41

Figure 14: Visualisation of the exhibition room, made by Zario Vries 43

Figure 15: Earlier blueprint of the touchscreen installation 45

Figure 16: Final iteration of one of the prototypes. Enschede 2021 47

Figure 17: The integration of the telescope 50

Figure 18: The exhibition setup at Cosmos Observatory Lattrop 2022 52

Figure 19: The mean scores of the custom controller installations versus the Xbox setup 56

Figure 20: Different dimensions measured during the playtest 58

List of Tables

Table 1: Stakeholder characteristics of the project 29

Table 2: Requirements from all clients 30

Table 3: Topics of interest for creating the installations 32

Table 4: Stature of Dutch children between 10 and 15 years old. Molenbroek & Jürgens, 1997 42

Table 5: Stature, shoulder height and reach depth of children between 10 and 12 years old. Steenbekkers et al., 1993 43

Table 6: Calculating the SS values of game 1 57

Table 7: Calculating the F-value of game 1 57

Table 8: resulting measurements for the exhibit per research dimension 59

Chapter 1 - Introduction

Since ancient times museums have been educational and inspirational centres. The word 'museum' comes from the Greek word "Mouseion", which means "seat or shrine of the muses". A muse is the inspirational goddesses of literature, science, and the arts in ancient Greek mythology. They provide people with critical information about our understanding of the universe and themselves. Recently museums have found another purpose. Since the 1970's, they have become a key element of the tourism sector and an important contributor to the urban economy (van Aalst & Boogaarts, 2002). This shift is also reflected in other research institutes like observatories as they serve the same role as museums. These establishments have now transformed into a space for entertainment and learning for visitors from all sides. This creates a new concept called 'edutainment'.

What is more, museums are being forced more and more to generate their own revenues as they started competing in the leisure market (McIntyre, 2009). They are thereby increasingly dependent on the buying power of the 'consumer'. Museums and galleries are now actively seeking out creative interface systems to encourage interaction with the visitors through computer-mediated displays, while keeping the technology in the background (Geller, 2006). To attract visitors, museums can introduce new technologies and change from static displays of information into active, or interactive, experiences (McIntyre, 2009). Nevertheless, the use of interactive technology in exhibitions can still be improved. Museums have the possibility to use knowledge and equipment available to explain scientific topics in a new fun and innovative way.

Current exhibits have the potential to give more engagement and knowledge to visitors. Specifically, interactive installations will be interesting to look at as the new focal point for the museum of the future. They have the potential to create unique, unusually tactile, and sensory experiences with the use of unique hardware and software. Especially the hardware is important as previous studies show that visitors often do not engage with text labels located on walls, or with printed materials (Ali et al., 2021). But not all hardware can provide an appropriate solution. The standard keyboard-mouse-and-screen setup might seem out of place in a museum (Geller, 2006). Instead, custom controllers might be a better solution. Custom controllers are uniquely designed hardware that can be used to receive input and send it to the device to turn it into an interaction. In most cases this refers to game controllers where the controller is used to control a character or other objects and their actions.

Currently, one of the museums that is actively innovating is the Cosmos Observatory Lattrop in the Netherlands. Lattrop is known as one of the darkest places in the Netherlands and therefore perfect for stargazing. The problem with observatories is that they mostly operate during the night. To keep the collection up-to-date and be able to open during the day, this museum wants to expand with an exhibition including solar watch telescopes. What they require is three different installations to attract visitors around daytime. The goal of the planned installations is to teach about different aspects around the sun. One installation about the solar system, one centred around the inner workings of the sun and one about the connection between the sun and the earth. To create this exhibit, they contacted the foundation GameLab Oost. This foundation is the largest serious gaming company in the East of the Netherlands. Within the foundation, a multidisciplinary team of students from various disciplines of higher educational levels work together on executing this project. Together with Cosmos observatory and Gamelab Oost, a plan of approach was made. They decided that serious games can help accomplish their goals. Serious games are defined by Martin and Shen (2011) as "an activity consisting of participants, goals, rules, and challenges with a purpose beyond entertainment". In the context of this project, the games in question are computer games. To play said games, the decision was made that custom hardware is needed fitting the museum. The installations are made together with the During this project, the development of games was done together with two different teams. Other tasks were done together with other professionals in the sector to create a successful final product. From development to final product took eight months, from September 2021 until April 2022.

For this graduation project, the primary challenge is to create the physical controllers that match the inputs of the games and enrich the experience compared to regular controllers. Each of the installations will need a custom controller as the design of each game is different and they require different types of inputs from the user. Furthermore, having different custom controllers for all of them will increase the diversity of interactions the user can have inside the museum, thus keeping them engaged in the educational process. The design of the custom controllers needs to be unique from each other, while still following the requirements that came out of the research. The resulting design is tested using prototypes connected to the games developed by the team within GameLab Oost. The results from the prototypes were used to create more elaborate installations that were presented at the Cosmos Observatory Lattrop.

1.1 Research outline

This research report tries to find a way to further innovation of the design of hardware in museums to create the best possible visiting experience. This was done with principles of Human Centred Design (HCD) in mind. The solution is researched by rephrasing the need for knowledge into one main research question:

How can custom controller installations improve serious games for visitors of a museum exhibition?

To investigate this question, three aspects were explored. The general visit experience is about edutainment, which is about learning and entertainment. The entertainment happens through engaging activities. Therefore, the first aspect is about engagement. It is important to find out what keeps visitors engaged throughout the exhibit and how to create one connected experience. The outcome should be that the visitor wants to engage with the exhibition and that they accomplish what they want from their experience. Second, the educational value for the visitors is looked at. The challenge of serious games is making the games intrinsically compelling, while not sacrificing on the player's learning experience. Adding a custom controller can influence the balance of the edutainment present, making it more about 'fun' interactions than learning. Therefore, more exploration around the balance of edutainment is needed, that can be tested through making the installations. Third, interactive installations often use physical interaction through custom controllers. In this report, the benefits of those custom controllers will be explored and compared against traditional controllers like touch screens or a mouse and keyboard. The hypothesis here is that interactive installations will result in a better experience in a museum setting compared to a traditional controller.

The three aspects discussed boil down to three sub-questions that will support the main research question.

1. *What is the most important when enriching the engagement in a museum?*
2. *How can serious gaming installations balance the edutainment present within the game?*
3. *What benefits do custom controllers have compared to traditional ones?*

These questions will be answered through an extensive research process where at the end a product will be developed to aid and test the research through real life application. The first step is conducting systematic literature research. The outcome of this research will be identifying all the main design aspects that are needed for making the custom controller. Also, aspects where further exploration is needed are revealed by the results. Next, in the state of the art, interviews are conducted with designers in the field to gain more practical information around the creation of interactive installations. The experience of people who test and put design into practice can help to ensure the design is reliable and achievable. Additionally, as part of the state-of-the-art museums were visited to observe several existing designs in action while users interact with them. This was done because, according to the principles of HCD, there needs to be a clear view from both the designer and visitor's perspective.

Finally, to conclude the research process three installations will be iteratively designed. The design process will be based on the Design Process for Creative Technology (Mader & Eggink, 2014). This is done in four phases: Ideation, Specification, Realisation and Evaluation. During the process, there will be more findings about the design and the design process. Once enough knowledge is collected, the theory will be tested using physical prototypes of three custom controller installations. Based on the prototypes, formal installations are developed for Cosmos Observatory. At the museum, a representative target audience can then test these installations. The results of the prototype testing will determine the overall effectiveness of the installations and will allow for checking if the theory matches with the real-life results. After the test, final conclusions are made, and a reflection can be done over the entire design process. The results of the research will give more insights surrounding the use of custom controllers in museum installations and also answer all of the research sub-questions. Ultimately, these answers will provide a final answer to the main research question.

Chapter 2 - Background

2.1 Context

The background research is based on the knowledge that needs to be obtained from the research's sub-questions. This research will be an important foundation to draw conclusions from and to build upon when bringing theory into practice by building the installations for the Cosmos Observatory.

The background research is split into two parts. A literature review and the state-of-the-art overview. Together they form the foundation for all the information needed to execute the project with GameLab successfully. The literature review looks at the three sub-questions individually to find information from literature that is as specific as possible to the questions at hand. The state of the art will give additional information to the possible design of custom installations. State of the art describes the current state of the development of technology and methods that are applied in real life. The section dedicated to it takes a critical look at how scientific insights are currently put into practice. It is divided into three parts. First, it looks at existing interactive technology to see what is popular and why. Second, an interview with an expert that is currently working in the field brings more information about the design process and its results. Finally, museums with innovative technological installations are visited in order to study users' interaction with the state-of-the-art exhibits. The conclusion of the background research will help obtain the information used to answer the main research question.

2.2 The enrichment of the museum engagement

When visitors engage with an interactive installation, it is important that they stay engaged for longer periods of time (Hornecker & Stifter, 2006). Museums want the visitors to be entertained, while the visitor also wants the experience to be worth the time and money investment. There are other factors that are less obvious that users want out of their experience. Visitors seem to come with an urge to learn and reflect upon the subject and themselves (McIntyre, 2009; Long et al., 2019; Back et al., 2001). In context to the project, Cosmos should make sure there is enough information available in the installations. The information about the sun should help the visitor put things into perspective. Furthermore, the installation can make the visitor question their environment. An example would be if the user asks themselves "How does the sun affect the average person?". Pisoni et al. (2021) proposes that the experience of a visitor is shaped by three interacting context factors: the personal context, the physical context and the social context. The personal context relates to the personality of the visitors including their knowledge and experiences. This can vary a lot between visitors. The physical context refers to the museum setting itself and its ambiance. The atmosphere of a museum can invoke different sentiments in a visitor, including how inviting it is to freely explore. The socio-cultural context is the cultural background of the visitor. Cosmos Observatory mostly gets visitors from around the region, which is the east of the Netherlands and some Germans as they lay close to the border. Considering their background increases the involvement of these visitors. Looking at the current situation at the museum this is already present, as the presentations are also done in German and facts about the region are included. These three factors can be found spread out in several research studies and can be considered as important.

The engagement starts already before the visitor is aware of it. The space and place where an interactive installation is placed is important for the successful engagement of users (Akpan, 2013). Thus, since the installations are placed in an environment dedicated to learning such as a museum, can already encourage the user to interact with them. Human-computer interaction (HCI) often assumes that the user is aware of the computer in the first place. This is not necessarily the case for public displays (Müller et al., 2010). What people focus on at any given moment is determined through a blend of their unconscious desires and their conscious will (Schell, 2020). To attract visitors, the installations must look or sound interesting, beautiful, or innovative (Hadjakos et al., 2015). Even when the installation is not in use by someone, it should grab the visitor's attention. This should be done in a way that is not overwhelming or distracting as to make the interaction threshold lower and as to not scare the visitor away. Next, the design of the installation should use familiar elements to attract visitors. Having prior knowledge of something makes the threshold to interact lower (Pisoni et al., 2021; Hornecker & Stifter, 2006). When designing the exhibition, it should be a cohesive experience where everything in it is connected and conforms to one general theme. In the case of Cosmos, this can be thematic to space, like control panels or sci-fi movie props.

The primary benefit of basing a design around a single theme is that all of the elements will reinforce one another, since they will all be working toward a common goal (Schell, 2020). Ali et al. (2021) suggests that there are two broad technological approaches to enable the exploration of connections between different artefacts in the exhibit:

1. Trajectory: where visitors walk from item to item and their experience is tailored based on what they have seen so far and/or suggestions are made about related objects to visit.
2. Overview: where visitors can see an overview of (part of) the collection and manipulate items to discover relationships between them.

In the situation with Cosmos an overview experience would probably be preferable. The exhibit is situated in one open room, which should attract visitors from a distance with the view of the exhibit. The three installations have no specific order in which they must be used, but they are connected to each other with a unified theme revolving around the sun. If the games in the exhibit would be connected in a specific order, a trajectory would probably be preferable. This can be seen in historical museums where the order of the installations is a timeline. No matter how the exhibit is connected, if the experience is attractive and cohesive enough, it can become immersive. Immersion stimulates the perception of the visitor by bringing the person involved in the collection display. The visitor is not perceived as an outsider anymore, but rather feels as an active part of the installation. In this way the interaction threshold is lowered. Furthermore, immersion can be achieved using sensory output using large displays (Hadjakos et al., 2015), interesting visuals and audio (Hakvoort et al., 2020).

Moreover, designers need to take the user's physical state into consideration as different users have different physical needs. Most importantly the experience curve is shaped by their physical abilities, prior experience, prior knowledge and learning speed (Pisoni et al., 2021; Hakvoort et al., 2020). If an installation is not intuitive to use a visitor will quickly turn away (Long et al., 2019; Hadjakos et al., 2015). If the user has a physical disability, the lack of accessibility in the design can hurt the experience of the user (Burdea et al., 2021). Around 5.5% of the visitors are people with disabilities (Pisoni et al., 2021). Universal design advocates for virtual as well as physical environments to be designed to be accessible and usable by as many potential users as possible (Pisoni et al., 2021).

The socio-cultural context in particular can be a dilemma. Due to the increase in mobility and globalisation, museums tend to design their displays in a universal way. The choice for a universal design could be at the expense of a cultural background. On the other hand, the social aspect of installations is more certain to contribute to better design. Research has demonstrated that content that is visible for several people simultaneously can stimulate interaction between visitors (Hadjakos et al., 2015; Hornecker & Stifter, 2006; Müller et al., 2010). Müller et al. (2010) describes this phenomenon as the 'Honeypot effect'. Whenever a crowd of people had already gathered around the display, this crowd seemed to attract a lot of attention. This results in other people being much more likely to also attend the display. Social interaction can be achieved by allowing multiple users to interact with the installation at the same time. It is known that visitors often tend to come in groups, which is why social engagement benefits the experience.

To conclude, an engaging experience is achieved through easy accessibility with a low threshold. The user must land in a unique thematic environment with both familiarity and innovation. It should be engaging to all kinds of visitors. The user wants to learn and be entertained simultaneously. The experience must be immersive with sensory input and output. In Cosmos, the experience will need a clear overview of the exhibition room with the installations. They must all be sensory attractive to anyone coming in. To make the installations come together the whole exhibition can be unified and immersed with visuals and audio.

2.3 Motivate learning with interactive installations

People go to museums for both entertainment and educational purposes. The concern from museum practitioners is that new technologies like interactive installations will not give the edutainment experience that is desired and instead will turn the museum into an amusement park. Therefore, it is important that designers take these concerns into consideration. In the design, the entertainment should support the learning experience rather than overtaking it. Learning should happen throughout the whole experience. The user should learn both physical and cognitive skills. Both are considered important (Long et al., 2019).

To promote learning in the phase of initial engagement, there should be something arousing curiosity and that promotes questioning (McIntyre, 2009). Therefore, the design can generate quick engagement by providing an early success experience and simple, small amounts of information to start. Then the user can start to fully explore the content in the installation. What is more, it is clear that not all visitors enter a museum with the same amount of prior knowledge, cultural capital and resources, and also their attitudes, motivation and interest may differ (Pisoni et al., 2021). Therefore, the experience needs to be tuned to suit different kinds of visitors. Installations trying to teach something to the player must teach them at the adequate difficulty level and give them feedback. The quality of this feedback can exert a powerful influence on how much the player understands and enjoys what is happening in the serious games presented in the installations (Schell, 2020)

Some installations will make use of serious games. In the context of this research, its main purpose is entertaining the visitors of the museum, if possible, while also teaching something in the background. If the difficulty curve is too steep, the visitor will become frustrated and stop early on (Hakvoort et al., 2020). For each user, the experience should start simple and increase the complexity level of the information presented depending on the user (Hornecker & Stifter, 2006). The challenge must be at a level that is just beyond the learner's skill level, but not so far that they get discouraged (Burdea et al., 2021; Long et al., 2019; Schell, 2020). What can also help is to enable the user to have a customised experience, where the designer considers personal time and space considerations for each visitor (McIntyre, 2009; Pisoni et al., 2021). To keep the user entertained the experience should immerse the player and follow them at their own tempo and challenge level. The challenge level can be adjusted by thinking about the adaptability of the system. Adaptability can mean that the people can adjust the system themselves or that the system adjusts to the player automatically. The adaptability needs to be almost instantaneous, and it needs to be highly responsive to ensure no frustration happens. (Burdea et al., 2021). This helps in tandem with making sure that the skill level is at just the right level for the player to enjoy the game. It will keep the player in the flow of the game and be challenged by it.

The longer the user engages, and the longer the installation keeps their attention, the more learning possibilities there are. Attention is defined as a cognitive state in which a child focuses on a selection of available perceptual information (De Greeff et al., 2018). If the user is focussed, they get in a state of creative expression. Creative expressions give participants more opportunities to learn. Prolonged engagement also indicates that visitors find an exhibit engaging and interesting. Somewhat orthogonal to duration is the intensity of the mental engagement with the content (Hornecker & Stifter, 2006; Pisoni et al., 2021). Continued reflection on the content and the environment is important in facilitating learning (Pisoni et al., 2021). Additionally, designing to facilitate reflection and mental-model revision can encourage deeper engagement and creative expression (Long et al., 2019; McIntyre, 2009). As a final note, it might be interesting to consider the use of physical interaction. Increased physical activity possibly improves children's academic performance (De Greeff et al., 2018). Physical activity has the potential to affect our interpretations and make learning experiences more intuitive and engaging

(Back et al., 2001; Long et al., 2019). The same can be said for the use of other sensory stimulations. One example is multimodal reading where reading combines several sensory modalities such as sound, text, graphics, and tactile sensation (Back et al., 2001). The use of these different stimulations can be debated though, as further research is needed.

2.4 The benefit of custom controllers vs. traditional controllers

No matter what the personal goal of the visitor is, there should always be interaction between them and the installation. This interaction is done through a physical interface. The interface is everything between the user and the game world (Schell, 2020). The interactive installation with its buttons, screen and other physical elements is all a form of an interface. The focus of this project is exactly on the physical interface, specifically controllers. As controllers are input devices, they must receive actions from the user. These controllers are an important part of the visit experience. Instead of using standard interaction setups (e.g., mouse, keyboard, computer screen, ...), exhibits can use non-standard input and output devices to provide an innovative appearance (Hadjakos et al., 2015). This is way more intriguing for visitors as these devices provide interactions unavailable anywhere else. However, the exhibit should also be easy-to-use, and that ease of use and simplicity should also be conveyed visually (Hadjakos et al., 2015). Moreover, in multiple studies, visitors have also stated that using physical hardware components over virtual displays (e.g.: touchscreens) is preferred (McIntyre, 2009; Hornecker & Stifter, 2006). The interaction in turn can have a positive influence on how well one can focus on the game, because they must be conscious with the buttons/attributes (Hakvoort et al., 2020). This is especially the case if the input has haptic feedback to help the user (Hornecker & Stifter, 2006). If the user must wait before knowing what effect the action caused, they will quickly become distracted and lose focus on our task. When feedback is immediate, the user can easily stay focused (Schell, 2020).

Long et al. (2019) proposes dividing the engagement into three stages. At the start, the user explores the installation through individual components (initial engagement). Next, the user slowly explores everything the installation has to offer by using components of the system together or executing short sequences of actions (exploratory engagement). Once they are familiar with the components, the visitors can use different components together and execute more complex sequences of actions (expressive engagement). In this last phase, the visitor will fully immerse and explore the creative limitations of the installation.

When the visitors start interacting with the custom physical installation, there are multiple benefits that a custom controller can bring. Firstly, familiar objects can be used in the interaction. Some examples are installations using a book form to better the reading experience (Pisoni et al., 2021) or a globe to simulate the form of the earth as seen in figure 1 (Companje et al., 2006).

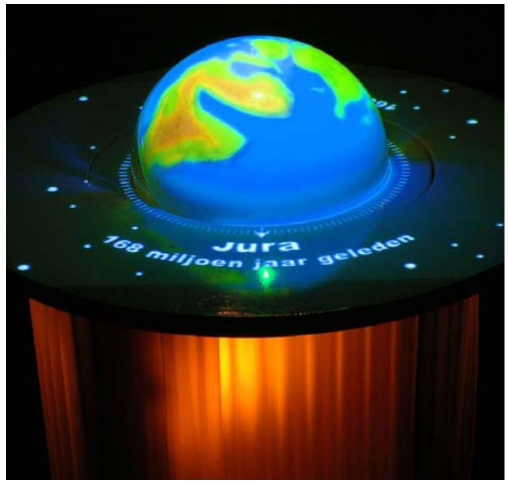


Figure 1: A prototype of Globe4D with a projection of the Earth's continents 168 million years ago (Companje et al., 2006).

The designer should consider that the physical form is sturdy, with invisible hardware (Hadjakos et al., 2015; Geller, 2006). The hardware becomes invisible when integrated as much as possible in the background, where the user cannot see it. The form factor of the installation should also be designed to be accessible to users with different physical disabilities. What is more, if the hardware controller is paired together with sensory feedback, the visitors can appreciate the installation in an intra-personal way by fully immersing them (McIntyre, 2009). It can heighten both the visual and other sensory experience of a visit.

The last aspect that is addressed and discussed in multiple literature papers is the ability to use custom controllers to make the installation into a social one. Visitors tend to come in groups. From the known research, making a social installation can be done by making both the input and output visible to as many people as possible. An environment will open for comments and discussion which will in return attract more people (Hadjakos et al., 2015; Hornecker & Stifter, 2006). Even the fact that the user of the installation is performing for others can be considered a positive interaction with all visitors (Hornecker & Stifter, 2006). A designer can also choose to make the installation available to interact within groups itself. At least two persons should be able to use an interactive exhibit at the same time. This also allows for the possibility to keep up with a constant stream of visitors (Pisoni et al., 2021). Alternatively, there should be a simple way to hand over the control from one user to another while still providing a meaningful interaction (Hadjakos et al., 2015).

2.3 State of the art

2.3.1 Available interactive technology

When building an installation, it is important to know what options are available in terms of hardware. Although many hardware installations use custom made hardware, existing hardware can both give inspiration and cut time costs by using existing components. These products can give a unique experience with complex hardware made for a specific purpose like active learning or entertainment through games.

One of the currently uprising technologies is Virtual Reality (VR) and Augmented Reality (AR). These are physical platforms where synthetic sensory stimuli make the user immerse themselves in a virtual environment. VR is made to replace the real-world sensory environment to land in a new one. Some of the most well-known platforms are the [1]HTC Vive and the [2]Oculus Rift. Both systems use a setup with a head-mounted display (HMD) with a stereoscopic display inside and two motion controllers for both hands. The system uses input from gyroscopes, motion sensors and buttons. The output is done through external screens, headphone speakers and haptics. AR on the other hand, adds to the real world's environment to give new possibilities. Some examples are the [3]Microsoft HoloLens and the [4]Magic Leap One. The general form factor of AR devices is like that of a VR device. They also use an HMD with motion controllers, hand gestures or even voice recognition. Unlike VR, AR uses a head-up display (HUD). A HUD is a floating user interface over a user's general view of the real world. This can integrate the virtual environment with real life tasks and objects. For now, some examples are projections of people in video calls, projecting clothing on people for research purposes or educating about anatomy using a model of the human body. Users react strongly when first experiencing immersive VR and AR. Seeing the stereoscopic graphics pop out of the screen, picking up a virtual object with their real hand and realising that head movements change their view of the virtual world all provide a unique experience (Bowman & McMahan, 2007).

Projection is another popular form of making innovative interactive hardware. Projections have the benefits of being sturdy, cheap, and scalable compared to traditional displays like television screens. Technologic invisibility is also a requirement for commercial installations and can be easily achieved with projectors (Geller, 2006). Products like [5]Lü, [6]LUMOplay and [7]Springlab use overhead projectors that project on the floor and/or walls. The user needs to move or throw to make interactions happen. This can be interactions like walking on the floor to play football to throwing actual balls against the wall to score points. Input is most commonly sensed by visual sensors. The [8]Azure Kinect is one example of such visual sensors. It contains a depth sensor, a RGB camera, microphones, an accelerometer, and a gyroscope. Sensors like these can be used to recognise specific body parts and their movement or other specific objects. One of the most notable concerns with overhead projection is shadows casted by the user. The issue with shadows can possibly be solved using double projection from two sides. The second projection will help by covering the shadow. However, double projection has its own issues, as the resolution is almost certain to be off and it will cost more.

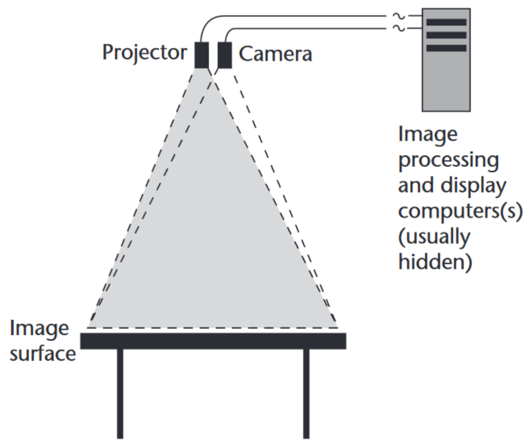


Figure 2: A simplified diagram of how a typical projection system works (Geller, 2006).

The other common way to use projectors is table projection. Tabletop displays encourage a homier, more-familiar, collaborative atmosphere and provide the ability to increase a display's interactive area. The user can use it from all sides and interact with different people simultaneously. Because of the form factor it is possible to hide hardware inside the device. There are two general form factors. The first is overhead projection, where the projector is above the table. One example is the [9]Tovertafel, which uses overhead projection to its fullest by being able to project on any table surface. The other form factor is rear projection. It uses projectors hidden on the inside of the table to project onto a transparent surface. Rear projection eliminates the issue of having shadows. An example would be the [10]Euclideon Holotable. If using overhead projection, capacitive sensors can be used under the surface of the table for registration of touch. The form factor also allows for placing objects on the table that can be recognised from the overhead camera. One interesting example of this is the use of projection mapping. Projection mapping uses a depth sensor to alter the projected surface. [11]UC Davis Open-Source Sandbox is an example of this, using the depth to make water flow simulations based on the height of the sand to create a rugged landscape. Something similar can be found at the NEMO Scientific Museum in Amsterdam, the Netherlands. In the Water Power exhibition, there is a projection mapped installation available made of a solid shape for water to flow through. The users can place sandbags to block certain paths off or open drains to let the water go out again.

Figure 3: Children play with UC Davis' Augmented Reality Sandbox at the 2016 USA Science and Engineering Festival. (Segale, 2016)

2.3.2 Expert Interview with 100%FAT

During the research phase, an expert interview was conducted. The difference between literature and practical application is not always one-to-one. Therefore, an interview with practical examples can shed a light on how theory is put into practice. The purpose of the expert interview is to get a better understanding of the development of interactive installations with custom controllers. The important aspects of their design methodology would be viewed to see what works and what not. Next, the design process of the installation itself would be taken into question as not everything works in every situation. Certain constraints and unknown variables can alter the design process. At the end of the interview there would be a better understanding of possible pitfalls and what is the most important to consider from the theoretical foundation made in the literature review. The notes taken in the interview can be found in Appendix A.

[12]100%FAT is a creative agency and producer of customised interactive installations who combine hardware, software, and content into a complete experience. They have done multiple projects both in and outside the museum industry. For example, 'The Sky' is an interactive light artwork in the World Expo 2020 Dubai. The Sky presents an autonomous light show in which all imaginable air and weather images are shown. The Brorfelde Observatory Experience is another example. This is an exhibit for the Brorfelde observatory in Denmark containing two different interactive installations. The 'Do It Yourself Lens-setup' is an analogue installation where the user can experiment with different lenses. The 'Zoomviewers' installation is an optical instrument where you can insert physical disks to access views about space. Once they are inserted, you can zoom impossibly far into different things like the moon or neighbouring solar systems.

The ideal design process according to them happens in 4 steps: Information gathering, Brainstorming, Designing and Execution. It is an iterative design process which means that often the design should be reviewed and adjusted. If the designer's relationship with the client allows it, the creation can be done in a co-creation process. Co-creation can form a better understanding from both perspectives of what the installation needs and why.

Figure 4: Zoomviewers at the Brorfelde Observatorium Experience. (100%FAT, n.d.)

During the information gathering process the designer should look at important aspects that need to be considered before starting the project. It is very important that every part of the information gathering needs to be written down. What does the installation need to do? Installations convey certain emotions or information. The client will preferably provide this information. The constraints of the project are also equally important. What is the available space? What are the possibilities in the available space? Some installations require electricity, a dark room or need to be weather resistant if they are placed outside. Sometimes there is limited space where the installation takes place or it is in a room full of other installations, in which case the cohesion of the exhibit is important. Something that is sometimes overlooked is the available budget as it can make or break what possibilities there are. Museums are often funded by government subsidies and a lot of the subsidies go to maintenance. This makes investing in new installations difficult. Once all the information is clear for the designer, the development cycle starts.

Brainstorming sessions are used to come up with ideas for installations. In 100%FAT, the whole team comes together to hold creative ideation sessions. Ideas can flow from everyone. Any input, feasible or not, can help the idea improve. To gain inspiration, a designer can also look at different media. The cinema industry sometimes published case studies online explaining the design process of certain scenes. Other media, like game designer interviews or hobbyist engineering videos can also be used as inspiration. These videos often go in depth into specific domains that can be useful to the installation designer’s project. Once the idea is more solid, a mood board can help in visualising what the idea is. Mood boards are visual presentations containing images, text or other things. A mood board is also very useful for presenting the idea, as visuals are considered important for most clients. If the concept is approved within the constraints of the project, the design phase can begin.

An iterative design process combines design and execution in phases to optimise the given experience. Design builds upon the brainstormed idea by making a specific plan for all the components in the installation and how they should be put together. To avoid later problems 100%FAT starts with designing and building the hardest parts first, as it will show how feasible the design is and to ensure that it remains within the given budget and time. During the building process everything should ideally be tested with end-users. This can take time and effort that designers might be unable to afford. In practice, testing will mostly be done with the most accessible people, like co-workers or in a better case, the client. Although useful, testing with this group can form problems, as these users are too experienced with the content. Therefore, this test group is not representative and inclusive enough to show potential problems in the design. To avoid some of the problems that a designer might encounter, user stories can also be useful. User stories provide an informal view from the end user's perspective using a written description of what the system is and how the user and the designed technology interact.

The design process does not always work in practice. Depending on the client, different parts of the design process can be done by different parties. This can cause issues as some more artistic design companies might be unaware of the technical problems that can be encountered later on. In this case, good communication is key. Another way where the design process is ignored, is if the client makes a proposal where multiple parties compete to receive the project. The winner is often decided based on their price and design. The problem for design companies is that they compete against hobbyists and freelancers that often ask for a sharply lower price, while delivering a project that is decent at most. Another disadvantage is the limit in time to present the design. To make sure that it is met, creative agencies like 100%FAT are required to skip ahead to the design phase to get an estimated price as soon as possible. Later, the company can work backwards to improve the design, when it is more certain that the project is secured. If all possible problems in the design process are accounted for, it should help the designer in their process.

100%FAT has a similar design process as the Design Process for Creative Technology (Mader & Eggink, 2014). It uses a spiral model in different phases, while also designing iteratively. As builders of creative solutions, 100%FAT sees the benefit of working with active participation and physical components. What the interview adds is real scenarios and problems that can happen during the process and how to deal with them. Sometimes the design process cannot be followed due to the constraints of the project. To mitigate problems, they try to keep communication with the client as a priority. Communication is often overlooked in the explored research of this report and instead the researchers strictly focus on the ideal design process and results of the design.

2.3.3 Interactive Museum visits

During the research, a couple of visits were made to Museums with exceptional interactivity and design. The visits were made to support and control the theory presented during the literature review. All the visits were done in a group, together with a person inside a wheelchair to study the basic accessibility of the museums. During the visit, notes were taken based on observations and interviews with employees. These notes can be found in Appendix B and C.

The first visit was the NEMO Science Museum in Amsterdam. According to NEMO, their mission is to bring science and technology closer to the public in an interactive and accessible way. They do this by having multiple interactive installations that are shaped as science experiments. They contain sensory experiences and bright colours. The installations play with elements like water, wind, light, magnetism, kinetic energy, or even bubble soap. Even though most interaction was clearly targeted to children, the parents present at the time of the visit also interacted with the installations. According to NEMO, the most popular installations are the ones that are very visually appealing using experiments with large and out-of-the-ordinary effects. They are often also installations that let people perform in front of others. This correlated with the research found in the literature review.

The popular examples that were given by NEMO were visibly installations like a plasma ball, big soap hoops to let the user create a bubble around themselves and a giant mechanical installation called 'The Machine'. The museum is divided into different floors each representing one theme and a specific age group. Each floor scales up the target audience's age from children to adolescents. The lower floors with installations for children were clearly more focused on the playfulness found in science. The most used installations use big visual effects with moving parts. Later installations on higher floors like 'The Machine' are better suited for learning about more complex processes. The Machine shows the logistical process inside an automated factory using big machines. The difference that NEMO makes for the children is that the factory replaces traditional assembly components with plastic balls. The children can work in the factory by playing a minigame with the balls. They grab the balls, and a screen will tell them to sort the ball in the right hole. Another interesting installation is 'Project Earth!'. It makes the user play a game to shield Earth from comets, meteorites, UV radiation and solar winds. The game uses rubber shields that convert the input into digital movement. Like most installations in NEMO, they find playful ways to teach about real-life applications without text.

The museum does however have text spread out throughout the exhibits. It is mostly placed in a place that does not disturb the interaction and is more set to the side by printing it on the floor and the walls. The upside is that the attention of the user can be focused on the interaction. The possible downside is that people who are interested, need to put effort into finding the information first. It was clear that installations that were badly lit or put on the side were used less and often overlooked by visitors. The arrangement of the exhibit and the lighting adds more important information to the general visit experience, as they were both not thoroughly discussed in the research.

In terms of accessibility, Nemo has several adaptations to their exhibit, so it remains accessible. Their website offers special tickets for users with a disability, where the supervisor of the disabled person can enter for free. The website also has a page on facilities available for any kind of person. When the user wants to go to any of the upper levels, there are elevators available. Most installations were also usable by people with disabilities. The only thing that was sometimes difficult were installations that require the user to get on a platform or on a fixed chair. Some installations also required force and specific movement. Thanks to the abundance of installations available this was only a mild problem. The design of NEMO's accessibility can be useful to include in the research as possible key points to consider for the design of the exhibit and even the website of a museum.

Figure 5: A user having difficulties interacting with an installation due to the accessibility

The other museum visited was Corpus in Oegstgeest, the Netherlands. Corpus provides a unique experience as it makes the visitor travel through the human body from bottom to top. During the journey, the user gets a pair of earphones that are synchronised with videos. The whole rooms are designed and decorated to look like the different body parts they represent. This connects nicely with the findings in the literature research from Hadjakos et al. (2015) and Hakvoort et al. (2020). The real-life visuals, audio and animations make the experience very immersive and sensory stimulating. The unified theme also helps with this. In turn the user learns more by being able to visualise all the information that is provided. All the video and audio is set to take a certain length of time. The experience is guided at a pace dictated by the museum themselves. Dictating the pace goes against the recommendations from the research about time and space considerations for the visitor. There is a useful reason for this decision though. The museum wants as many people to be able to visit as possible and only a small group of people can go at the same time. A set time allows the museum to control the pace. It allows multiple groups to be inside the experience, if they are not in the same room.

Considering the accessibility, some options are already available. The tour can currently be done with users in small to regular sized wheelchair users. During the experience only a few problems were encountered for the wheelchair user present. Having the possibility to follow the experience equally to others is great. In the future the space can be expanded upon by allowing more and bigger types of wheelchair users. Overall, a lot of the positive elements found in the research can be found in this 'installation'. There are also still improvements possible.

Once the tour is over, the visitors land in the interactive section of the museum. In this section there are multiple floors with interactive installations. Most of them are interactive screens with information or small games to play. During the visit, the number of interactive installations had both positive and negative effects. While there was a lot of interactivities, it was clear that most interactions were relatively basic. Most installations were touchscreens. The user must press digital buttons on the screen to make interaction happen. This lacks the feedback or sensory stimulation. Because of the lack of continuing dialogue between the system and users, this could be named a static in-output instead of true interactivity. The users present were mostly attracted to the installation that had a more recognisable form factor. One of those installations is Kantine 'De Dag'. By using the shape of a regular school canteen, it attracts children to interact with it. The flaw of the installation was that the size was too big for children, so a stool was needed. This also meant that people in wheelchairs could not access this installation and some other installations as well. Overall, even with the possibilities present, the interactive section could still improve with some of the more intricate features that the research portraits.

2.4 Preliminary conclusion

In the literature research three important aspects were considered when analysing the custom controllers for museum installations. These aspects are the visiting space containing the exhibition, the learning process of visitors and the custom controller itself. These are all key details, as they influence the experience of visitors in a museum.

According to the found research, the general experience of a museum is one of edutainment where visitors want to have an out-of-the-ordinary, sensory experience. The visitor should land in an immersive world where they can explore and learn according to their own time and space consideration. This experience is made using innovative technology using alternative ways of sensing input. The most immersive technology relies on taking over the senses of the user as is seen in VR or projection with large screens. Immersion also happens when the theme is represented well with the decoration and music of the exhibit following the theme like in Corpus. The usage experience must be a democratic one, so it is accessible to as many different people as possible while not taking away from the experience. It should also be a social one to interact with each other and perform for each other. Making the content visible and central in the exhibit helps to make social interaction possible. Visibility is increased when making the focus points well lit up and using big effects.

People come to museums to learn and re-think. An installation can help learning by making the visitor aroused with curiosity. They must provoke questions about the content and the users themselves. The information available should be visible but not obstruct from the experience. To ensure the quality of the information, the client should be thoroughly interrogated and should ideally collaborate in co-creation. When interacting, there should be an early success that is on a level that every user can understand and complete. Then the installation should try to keep their attention to enter a state of creative expression. Make the installation adapt seamlessly to the skill level of the user to keep them engaged, while learning new skills at their own pace. This level depends on their cognitive and physical skills. While the user is learning, they must have the possibility to (self-)reflect.

A custom controller is a custom way to get input from the user and is an integral part of the installation. They have multiple benefits for an installation and the general visit experience. An ideal controller is a sturdy, easy-to-use physical controller with intuitive and familiar elements, while hiding the complexity behind it. These aspects can be ensured by testing with a variety of end-users. The installation becomes more immersive and intuitive when the controller creates a sensory experience with feedback. The easy-of-use can contain aspects like the size of the installation and the way the user needs to move. The height should be adjustable so both children and people with disabilities like wheelchairs can use it. All the interactions should also be within a short arm's reach. The controller needs the ability to make multiple visitors simultaneously engaged. Engagement in installations happens through the possibility of having multiple people using it or making it visual to a broad audience by using big moving parts in the design. The result should be a better user experience where the controller helps the user achieve their goal easily focusing on edutainment.

Chapter 3 - Methods and techniques

3.1 Creative Technology Design Process

The background research serves as the foundation to form the project with Cosmos Observatory and Gamelab Oost. The findings will be considered throughout the whole process. Design methods from 100%FAT can help in increasing productivity and prevent roadblocks from happening. One of the examples that will be used is a co-creation process, where the client will engage in designing the installations through regular meetings and feedback.

To achieve the goal of this graduation project, a design approach and methods needed to be established. The design process used is the Creative Technology Design Process (CTDP) by Mader & Eggink (2014). Just like 100%FAT, this uses an iterative design process, meaning that the current design will build upon previous ones. This iterative design process consists of four phases: 'Ideation', 'Specification', 'Realisation' and 'Evaluation'.

1. **Ideation**: In this project, the ideation phase is about how to solve the lack of unique interactivity in the museum. The custom controllers needed to have fitting components to fit the then developing games. Exploration is done through the expert interview conducted in chapter 2 and next, sketches and the morphological analysis chart were used. The morphological analysis chart resembles a matrix of rows and columns. It develops concepts for each product sub-function.
2. **Specification**: Next, the results of the ideation phase converge into a list of features to include in prototypes to test the feasibility of the design. Throughout the process, the features were tested with the stakeholders.
3. **Realisation**: Next, the final product will have a list of all the materials needed to build it, including electronics, the materials for the frame and how to execute the building through blueprints. The installations were realised in two iterations. The first is a real sized prototype, followed by the final installations that would be put in Cosmos. The first iteration is done completely individual, while the final installations would be made in collaboration with multiple professional parties. Because of pragmatic and budget-related reasons, these iterations were partially fused.
4. **Evaluation**: At the end of the cycle, the final installations were tested with a diversity of end-users. Conclusions were made about the design; the research and how further improvements could be made on the designs.

The CTDP uses a divergence and convergence model. In the start, the design space is opened to explore the design. Then, the design space is reduced back to the best solution based on the requirements and available knowledge of the designer. In this research, several ideas for controllers were made and then reduced to what satisfies the conditions that the client set. Next, the CTDP also uses a spiral model. It enables the designer to use findings in later phases to integrate back into earlier phases to go over several iterations of the design. This was especially important in the specification phase, where the feedback of the client would turn into suitable changes of the design. In the realisation phase, the design also goes through multiple more subtle iterations by tweaking the design to fit the available materials and limitations that pop up.

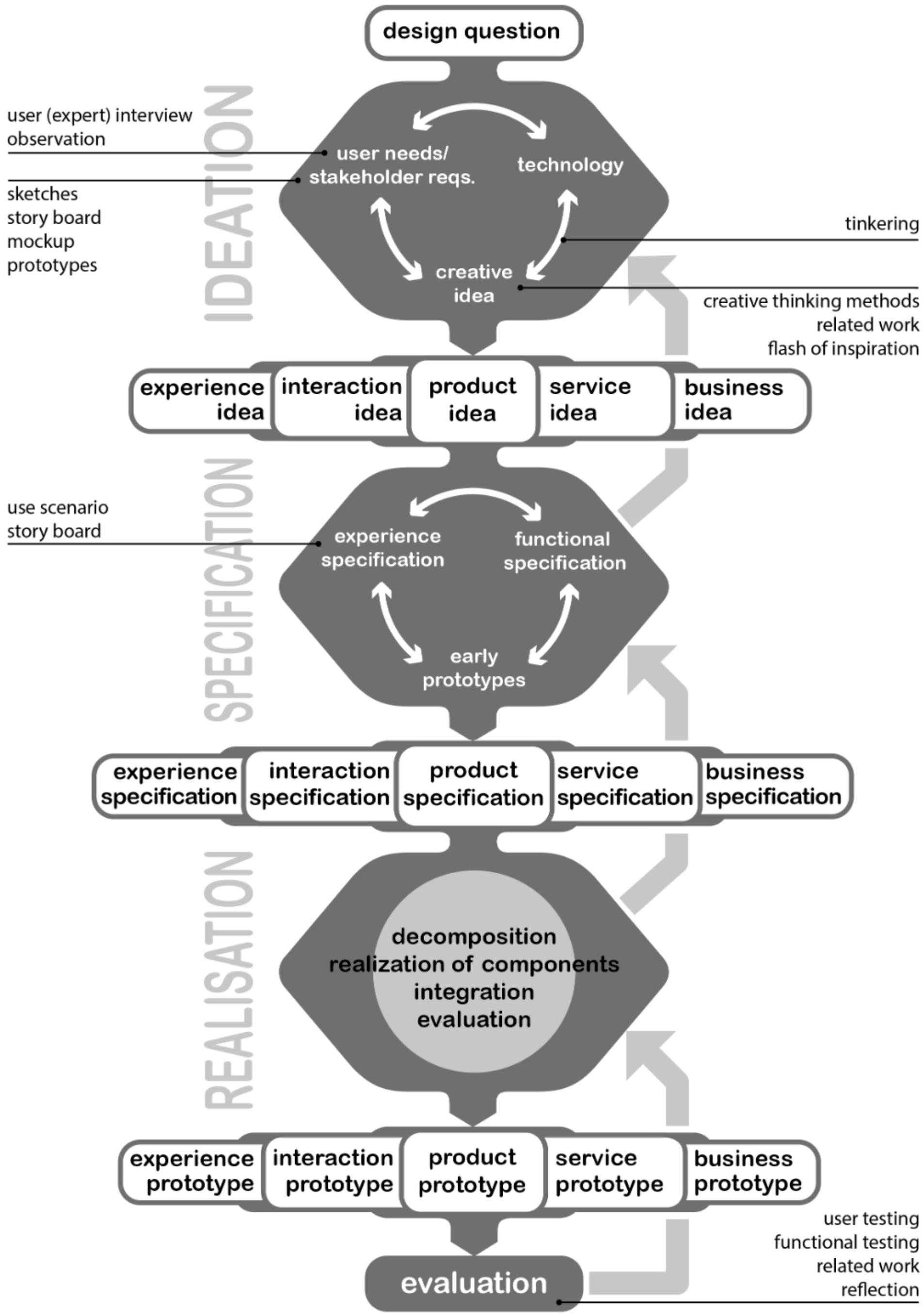


Figure 6. A Creative Technology Design Process. (Mader & Eggink, 2014)

3.2 The Scrum Agile Methodology

The development of the design of both the game and physical installation was done in close collaboration with the foundation GameLab Oost. The designs of the game and controller needed to integrate properly, and everything needed to be planned out together with the software team of 6 - 8 people and the project leader. The stakeholders from Cosmos Observatory also needed to be involved in weekly meetings. While the CTDP is useful for smaller research projects, its primary focus is not the specific interaction between multiple parties with different backgrounds. This project needed different departments to communicate changes in the design and progress regularly, as the design rapidly evolved.

The agile methodology makes sure that everyone understands the goals of the project and provides solutions in a fast and incremental way. The implementation used was Scrum. The creators of the system, Sutherland & Schwaber describe scrum as “a lightweight framework that helps people, teams and organisations generate value through adaptive solutions for complex problems” (2020). In a scrum team there are different roles. The Scrum Team consists of one Scrum Master, one Product Owner, and Developers. Scrum works in sprints. They are fixed length events of one month or less to create consistency. At the start of each sprint there is a Sprint Planning, Sprint Review, and Sprint Retrospective. Each day there is also a daily scrum meeting to communicate the progress. A new Sprint starts immediately after the conclusion of the previous Sprint. Within the team, sprints were held every one to two weeks and daily meetings were organised at the start and end of the day.

Chapter 4 - Contextual analysis

Before starting the development cycle of the project, the current context needed clarification. The project contains a lot of factors and stakeholders that could affect the outcome of the design at any point in time. To prepare for any future roadblocks, a contextual analysis was done. Here, the project is looked at from different perspectives to see what the goal is from each stakeholder in the project.

4.1 Stakeholder analysis

A stakeholder analysis is a tool to understand the behaviour, intentions, interrelations and interests of individuals and organisations involved in the project (Varvasovszky & Brugha, 2000). The design needs to satisfy the requirements set up from the research, while also fitting in with the ideas of the people involved in the process of making the design. What is important is that each stakeholder has different requirements and impact on the project. All the aspects are important to know beforehand.

In the project involving Cosmos, the stakeholder analysis was done during the start of the creation of the design. The development of interactive installations for Cosmos Observatory involved numerous stakeholders. With the knowledge of all the stakeholders, different inputs can be processed accordingly so that the final design is made as satisfying as possible. To define the position of every stakeholder in the project, first the main project goals needed to be set up. From the client's perspective, the goal is to make an exhibition around the sun with three games. From the research perspective the goal is to test the hypotheses of the research through design and prototyping. The results from the stakeholder analysis are put in a table. The format is based on the design of the stakeholder analysis of Varvasovszky & Brugha (2000).

Stakeholder	**Involvement**	**Interest in the issue**	**Influence / power**	**Position**	**Impact on actor**
The developer	Makes the final decisions and executes the development	Medium	High	Lead	High
University supervisors	Supports the developer in their research	Low	Low	Mixed	Low
GameLab Oost	Is contracted and paid to make the installations. Works with the developer.	Medium	High	Lead	High
Cosmos observatory	The client in need for the installations	High	Medium	Mixed	High
External	Are contracted to make	Medium	Low-	Mixed	Low

professionals	final iteration based on the prototypes		Medium		
The users	Will give feedback on the prototypes	Low	Medium	Non-mobilised	Low

Table 1: Stakeholder characteristics for the project

4.2 Project-based goals and constraints

This research is a part of a project of GameLab Oost and Cosmos Sterrenwacht. All stakeholders have certain interests and ideas that they want to accomplish at the end of the project. During the course of the project, new goals also emerged, and changes were made. New problems and opportunities came to light which shaped the project. There is great importance in the designs staying lenient. A plan B always needed to be ready in case of certain changes.

Underneath are the primary goals and aspirations of the stakeholders concerning this project. Some goals were set up at the start of the project like the need for hardware and the need for three installations. Others emerged later based on the developments and research in the games and hardware. Most of the later found goals were based on notes taken during meetings with the clients. The games were designed and produced during the design phase of the physical installations, resulting in some emerging constraints for the physical installations.

Goal	Source	Reasoning
Three installations	Cosmos Sterrenwacht	Making sure different aspects can be taught in different games
Installations suited for 10 - 15-year-olds	Cosmos Sterrenwacht	Main target audience found from prior research
Parents are also entertained by the installations	Cosmos Sterrenwacht	10 - 15-year-olds almost exclusively come supervised by a guardian
Budgetary limitations	Cosmos Sterrenwacht	Limit set by the funding for this project
Deadline for completion	Cosmos Sterrenwacht	Opening date of the renovated museum
Safety and sturdiness	Cosmos Sterrenwacht	Children tend to act wild (from personal experience clients)
Required information to be conveyed	Cosmos Sterrenwacht	Cosmos aims to teach the public about the Sun
Projectors for each	Cosmos	Visibility and unification of

installation	Sterrenwacht	installations (found later on)
Social distancing possible	Cosmos Sterrenwacht	COVID-19 restrictions for public spaces
Planet info UI game 1	GameLab Oost	Information should be displayed unobtrusively.
Spaceship movement game 1	GameLab Oost	Basic movement decided on for game
Atom combining game 2	GameLab Oost	Basic interaction decided on for game
Progress bar game 2	GameLab Oost	UI required for the game
Sun phenomena displayed game 2	GameLab Oost	UI required for the game
Time travel between scenes game 3	GameLab Oost	Core game mechanic
Display atmospheric data game 3	GameLab Oost	UI game mechanic
Rotational movement of player game 3	GameLab Oost	Basic movement decided on for game
Flexible amount of scenes (time periods) for game 3	GameLab Oost	Possibility for later adjustments (found later on)

Table 2: Requirements from all clients

4.3 Research-based topics of interest

In the background research of chapter 2, several aspects of the use of custom controllers in a museum context were explored. To help structure the results, this research used a literature matrix. The purpose of a literature matrix is to help a researcher identify important aspects of the study. These aspects are found through finding fitting answers per source for each sub-question of the research question. Afterwards a synthesis is formed on each sub-question to see how valuable and valid each aspect of the research is. The synthesis can be in a form of text or in this case a list of keywords. The literature matrix can be found in appendix D.

In the syntheses multiple important aspects are found that are important to test while creating a fitting installation for the Cosmos Observatory. The most important aspects were compiled together to form the foundation of the goals that the installations want to achieve and are highly important for the research. They were decided based on how often it was found in different literature and how well it was supported. The concluding important topics can be found in table 4 below. Sources are placed alphabetically.

Topic	**Source**
Physical interactions	McIntyre, 2009; Hakvoort et al., 2020
Well balanced usability (Intuitive / easy to use / Simplicity)	Hadjakos et al., 2015; Hornecker & Stifter, 2006; Long et al., 2019; Schell, 2020
Sensory experience	Hadjakos et al., 2015; Hakvoort et al., 2020; Schell, 2020
Immersion	Hadjakos et al., 2015; Hakvoort et al., 2020; McIntyre, 2009
Use of familiar objects	Hornecker & Stifter, 2006; Pisoni et al. 2021; Schell, 2020
Accessibility (disabilities)	Burdea et al., 2021; Pisoni et al. 2021
Sturdy	Geller, 2006; Hadjakos et al., 2015; Pisoni et al., 2021;
Invisible hardware	Geller, 2006; Hadjakos et al., 2015
Social experience	Hadjakos et al., 2015; Hornecker & Stifter, 2006; Müller et al., 2010; Pisoni et al.,2021; Schell, 2020
Visible to crowd	Hornecker & Stifter, 2006;
Appearance (Innovative / thematic)	Hadjakos et al., 2015; McIntyre, 2009; Schell, 2020

Table 3: Topics of interest for creating the installations

Chapter 5 - Ideation

Ideation is the starting point of a Creative Technology design process. In the ideation, the designer explores the problem definition as a design question, acquisition of relevant information and idea generation (Mader & Eggink, 2014). The design question was formed based on the order from one of the clients, the Cosmos observatory. The requirement of custom controllers came from the need of hardware to play serious games on.

In the research, multiple benefits were found to using custom controllers. Therefore, we strengthened the requirement for custom controllers to satisfy the need of hardware to play serious games on. The possible designs were explored thoroughly, not limited to one conventional form of hardware. To make a successful design, all the important aspects of the design need to be clear to the designer. The design aspects are based on the knowledge gained from the research, what the stakeholders want and what time allows.

5.1 Mind map

To create fitting concepts, the designer's creative space must open for creative solutions. There are multiple ways to draw inspiration and techniques to find possible solutions. The technique chosen to diverge possible ideas is mind mapping. Installations require different components that work together like the components, shapes, and materials. In the mind map, 4 main headers were chosen whereas many possible solutions were searched for: Inputs, outputs, physical forms, and sensors. In each of the areas as many solutions were searched for. Inspiration was drawn by searching already existing ideas and successful installations on the internet. The feasibility and other factors were not considered, as the point is to broaden the options as much as possible. The mind map was originally made op paper and then digitalised later. The resulting mind map can be found in Appendix E.

5.2 Morphological design

After finding possible components for the installations, the ideas for the design can start to be developed. User centred design techniques like mock-ups, sketches, user scenarios or storyboards are useful techniques to evaluate new ideas on a design. To make a more structured design process, the main ideation of the design was done through morphology. The morphological method's main goal is to achieve a schematic perspective over all the possible solutions of a given large scale problem (Zeiler et al. 2009).

To apply the morphological method a chart can be created. In this project this was done in excel. The morphological chart is formed by decomposing the main goal of the design task into functions and aspects which are listed on the first vertical column of the chart which consist of a column and connecting rows. The functions and aspects are derived from the program of demands which defines the outcome of the design process. Possible solution principles for each function or aspect are then listed on the horizontal rows (Zeiler et al. 2009). The morphological design chart can be found in appendix F.

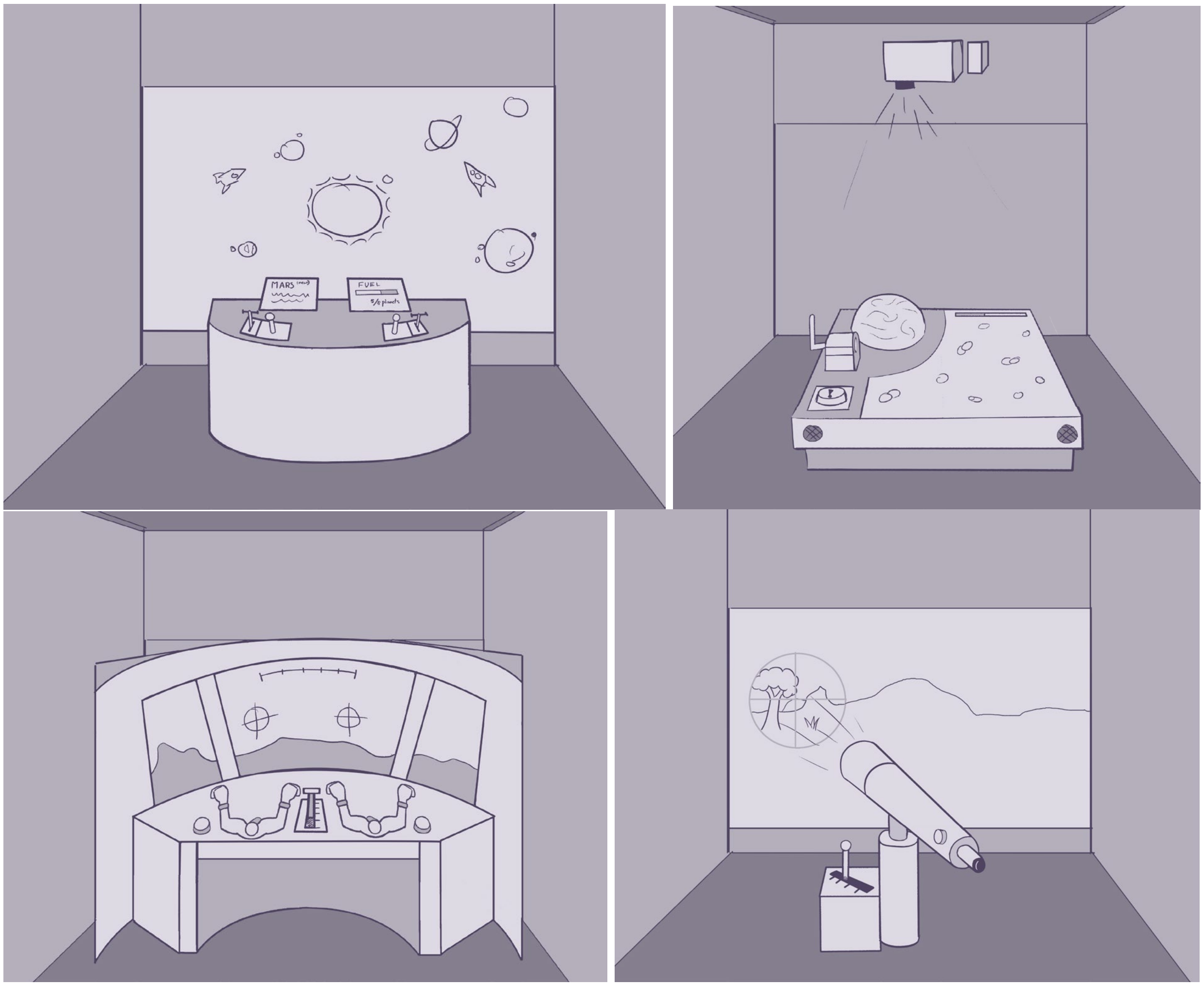


Figure 7: Some results of morphological design ideation in self-made sketches. Top-left arcade setup with large projection, top-right a projection mapping table, bottom-left a joined gaming console with custom steering wheel and throttle, on the right a telescope.

In this project, morphology was used by matching multiple components gained from the mind map to create a fully developed concept. There are three installations. For every installation, at least 5 concepts were thought out, where unique components were matched as much as possible to create a complete system combination. When the concepts ideation is done, there is a possibility to interchange components from different concepts. By merging later iterations of designs, the possible quality of the earlier designs can be elevated too. In figure 7, some of the results are displayed. These concepts contain elements making up the final ideas.

5.3 Results of the ideation

There are three installations with different unique serious games made for it. The final designs emerged by selecting from the list of the created designs and looking at what is the most plausible and fitting to the project. Afterwards the selected ideas converged to one fitting concept for each installation, while considering the goals of the client. All the components were rated on the difficulty level of implementation, the price of the components and the quality of the design. The quality was determined by factors like how suitable the hardware was for the game and commonalities between the installations.

5.3.1 Installation 1: Solar system exploration

The first game is about exploring the solar system. The game is 2D and works from a top view perspective. The game can be played with two players. Each player will fly around the solar system with a spaceship. They can discover planets and refuel their spaceship by landing on them. Once all eight planets have been discovered, the players win and the game ends.

The game is controlled by a table with classic arcade joysticks and buttons. A projector is used to display the gameplay. The big screen provides good visibility for many people, provides the opportunity for performances, and gives space for discussion and commentary. The installation is made to be played with up to two players to encompass the social aspect found in the background research. There is also a separate screen in the middle of the table to display extra information which, as seen in earlier game prototypes, might have cluttered the gameplay otherwise. The screen needed to be big enough to be visible when playing the game. The visibility of the smaller screen is something that needed to be tested later with the prototypes.

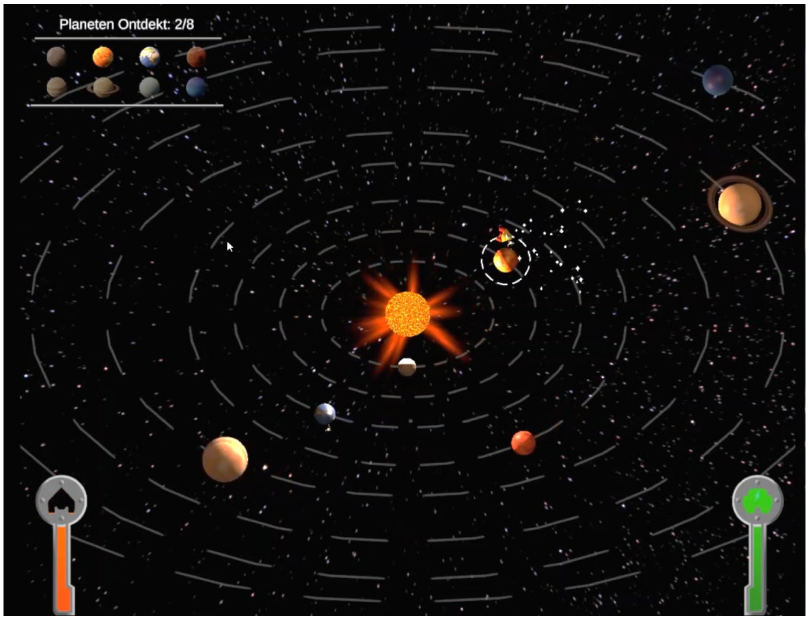


Figure 8: Prototype of game 1, made by GameLab Oost

5.3.2 Installation 2: Sun processes

The second installation contains a game about learning about the sun processes. Most importantly, nuclear fusion is explored. Nuclear fusion is the centre of the main gameplay. The user fuses atoms by moving them towards each other creating other new atoms. By fusing more and more atoms, the sun will slowly start to burn brighter. While the sun progresses, there are also phenomena like solar flares and sunspots displayed over time. Text will also be displayed when certain milestones are reached. Once the sun shines as bright as it can get, the game is completed.

The choice of custom controller for this game was to use a touchscreen. In some of the research the use of touchscreens was not supported because of the lack of feedback and physical components to play with. The choice was made anyway, as it was found to be natural and intuitive to use with the game. To quote Schell (2020): "When touch games first appeared, many gamers complained loudly. A touchable screen was a poor substitute for a gamepad—that is, when it tried to mimic a gamepad. Soon, games started to appear that would not have been possible without touch, and people felt very differently.". To comply with the research, the touch input can be implemented in a unique way, which can contribute to an innovative and unique appearance and experience. Three variations were proposed. A projection on a wall or table with a Microsoft Azure Kinect to register the inputs, an 87-inch pre-assembled touchscreen or a smaller touchscreen in a frame with a beamer projecting next to it.

The table / wall projection was rejected because of the complexity in the available time frame, while the big touchscreen was rejected as it was less unifying to the exhibit and less unique. The chosen form factor was the smaller touchscreen as a custom frame could be made that would fit in with the other installations.

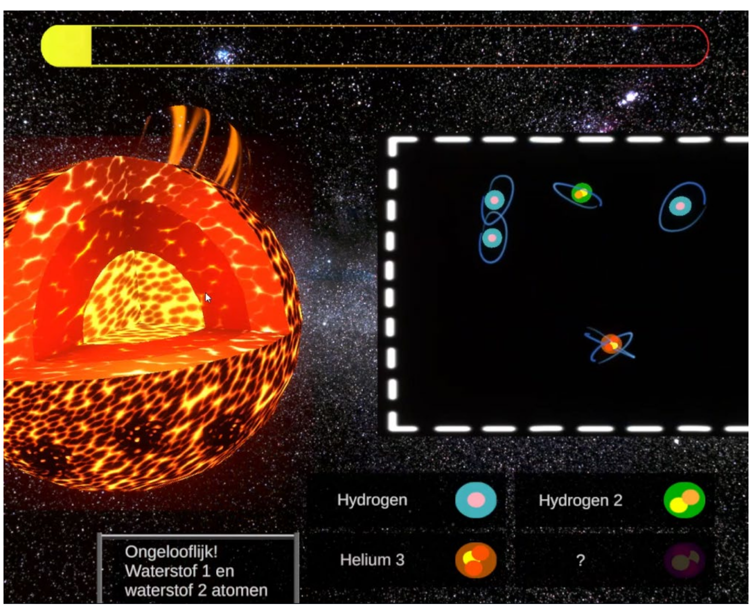


Figure 9: Prototype of game 2, made by GameLab Oost

5.3.3 Installation 3: Journey through time; The Sun and the earth

The third installation has a unique blend of custom controller and game, as there is more focus on playing with unique inputs, instead of focussing solely on elevating the game experience. In the game, the user will time travel to different periods of time on earth. The time periods are based on the life phases of the sun. For each time period there is a different scene, where the user can look around to explore the differences at their own pace by experimenting with the custom controller. The differences are marked with question marks as ‘points of interest’. The points of interest reward the player with more information, to understand what is happening in the scene. Information like humidity, forms of life and temperature can be found throughout.

The custom controller uses a table like the one used in the first installation as it improves the unification of the exhibition and cuts time in designing a brand-new form factor. It also comes with a similar projector. The difference between the first and third installation is the inputs placed on top of the table. This installation uses a telescope attached to the table that can rotate on two axes. The telescope controls the rotation in the scene. Another component used is a wheel or lever. With this, the user can travel to future or past time periods to explore more points of interest. Finally, there is also a button available to perform actions. As this installation uses more unique components, feasibility and integration needs to be tested thoroughly in the Specification phase.

Figure 10: Prototype of game 3, made by GameLab Oost

Through multiple iterations, three final ideas were created. One was made for each installation. They were sketched out to give a better understanding for the stakeholders. The ideas were not finished yet. They need to be better understood and refined to create actual physical prototypes and eventually be placed in the Cosmos Observatory.

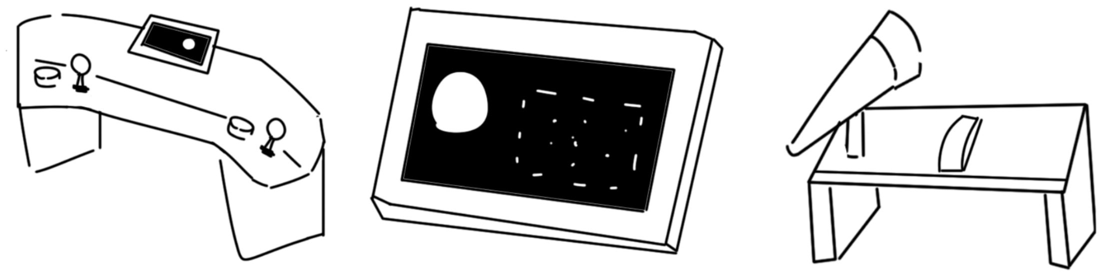


Figure 11: Final ideation concepts for each installation

Chapter 6 - Specification

The result of the ideation is a variety of potential ideas for the final installations. In the specification phase, the feasibility of the ideas was tested, and the possible ideas were then converged back into one. Afterwards, the final ideas got refined further until they satisfied the goals of the installations as much as possible. The installations got more thought out with details that ensured that the designs were user friendly and integrated properly with the technology inside of the installations. The further details are made, the more challenges will emerge that were not clear yet in the ideation phase. Any of the emerging problems are better tackled early, as this will always be harder in later phases of production.

During the specification phase, the shape of the installations will no longer change drastically, but instead they evolved gradually by adding important details and testing the design through visualisation and prototyping. Visualisation encompasses 3D modelling where general shapes, colours and compositions are explored. When a satisfactory result was achieved, blueprints were made based on the model and a prototype was made based on the blueprints.

6.1 3D model concepts

After the ideation sketches were formed, the installations were modelled using Blender and Autodesk Maya together with Zario Vries, the game artist present at GameLab Oost (seen in figure 9). In there, different iterations of the same concept were made to compare differences between details like comparing similar shapes for the installations with different positioning of components and angles. The decided theme for the installations was ‘space arcade’. To encompass the theme, the shape needed to fit with this concept. Other topics, like the height required for children and wheelchair users or making sure that it is safe, and sturdy enough were also taken into consideration when making the design. 3D visualisations help to see those details from different angles while also taking less time than making small physical mock-ups.

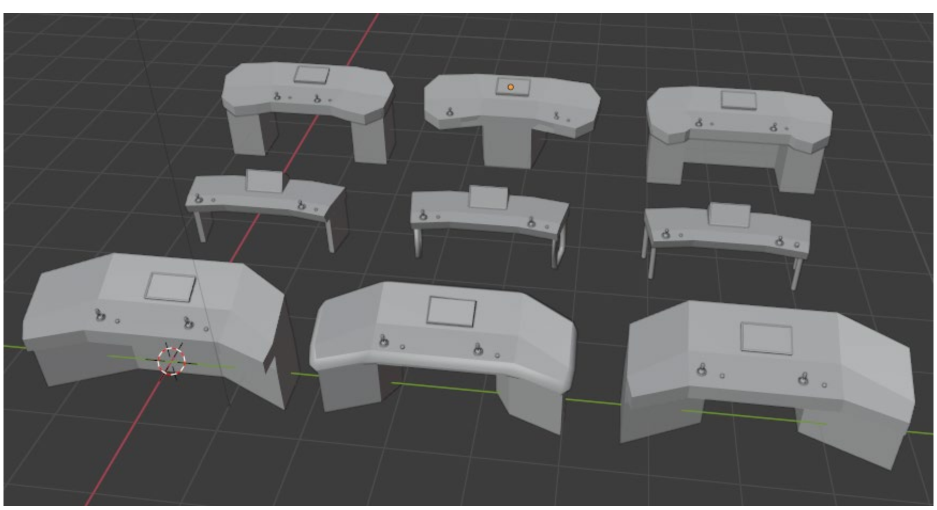


Figure 12: Different installation models to compare by Zario Vries.

There were different shapes and positionings used. The concepts were then evaluated based on how well they accomplish the goal and how good they fit the aims of the project. This evaluation was done through discussion with the artists at GameLab Oost.

The results for the two table installations were tables with a shape that takes inspiration from a giant controller and a sci-fi control panel. The tables are slightly tilted for better general accessibility. The tables also stick out in the front, for wheelchair users to access it better without hitting the legs of the installation. Each table has two big square legs on each side, which is a trade-off that had to be made. Two legs offer better stability and sturdiness than one leg, even if it reduces possible leg space on the sides. The thicker, square legs can handle abuse by users better than if thinner legs were used. Finally, all the corners on the tabletop are chamfered for the safety of the users, but they are kept angular to appease the space theme.

The result for the second installation was a 19-inch touchscreen with a custom frame. The frame takes similar design cues from the other installations. It has a squared leg holding up a frame for the screen that sticks out for better accessibility. The screen is also angled and has chamfered corners. Next to the touchscreen is a projector showing the gameplay for the audience.

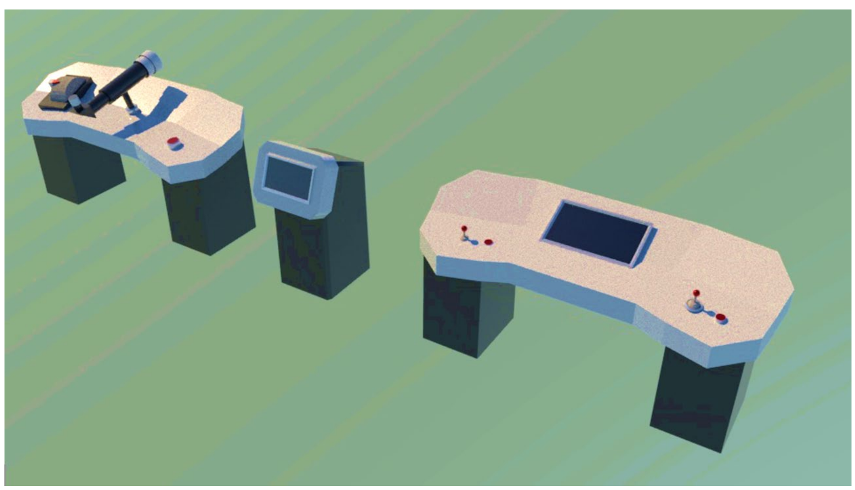


Figure 13: My implementation of the final concepts of the installations, rendered in Maya

6.2 Development of Blueprints

At this point in time, the ideas of the installation were almost far enough to start purchases and development. Before that is possible there needs to be a plan as this moment would determine what the final product would contain and what could be worked with in the future, in case of certain changes.

6.2.1 Budget plan

To start the development, a list of materials and components was needed. There was a budget given from the client, which would encompass the entire setup for the exhibition. The list of materials therefore consisted of the electronics for the controller, building the frames for the prototypes, building the final installations with the external labour included and hardware like computers, beamers, and speakers.

6.2.2 The hardware and electrical components

To make the custom controller, the most important part was working with the electronics. There are numerous ways to implement the electronics. The one chosen for this project was the Arduino Leonardo. This microcontroller was chosen because of the ability to process electrical inputs and automatically convert them into mouse and keyboard inputs for a desktop computer. There also is software available to convert any serial inputs to Unity, which was considered as a back-up. Mouse and keyboard inputs are easier to integrate in games than the serial input that Arduino's use. The games for the installations were made in the Unity game engine. Unity has standardised integration for mouse and keyboard. The easier integration also helps with any new games if they would be made in the future.

Connected to the Arduino are arcade buttons and joysticks. They are already designed for heavy use and are easily integratable in the table through screw holes and other attachment methods. The custom components also use sensors made for microcontrollers like Arduinos. The telescope uses a 3-axis accelerometer and gyroscope module, while the colour wheel uses a colour sensor.

To make the Arduinos work, they need to be connected to a computer. After some tests with the games, it seems that the computers need to be made for budget gaming. Gaming computers are in general bigger, so the size of the model found needs to be considered in the design of the frames. Next to the computers, there need to be beamers to display. The type is dependent on the space that is used. The room that is available for the exhibition is 5 metres wide and 8 metres long. The projection is done from a support beam in the middle of the room. Together with the visual artist from GameLab Oost, a 3D mock-up was made to visualise the room and see where the installations and beamers should be placed. The walls on the sides have a maximum of 2,5 metres, which requires short-throw beamers to get the desired size of the screen. Short-throw beamers are different from other beamers as they can project wide screens over a short distance. They also often have a lot of possibilities for key-correction, which fixes distortions when projecting from sharper angles. The last hardware piece is the speakers. Together with the sound designer at GameLab Oost, there was a discussion about how the installations could make sound effects and music happen without disturbing the other users and other installations. The solution was to use one general speaker system for one immersive soundtrack encompassing the whole exhibition room. The games will then produce their own sound effects using built-in smaller speakers in the installation. Once all the hardware components have been established, the frames could be adjusted for it.

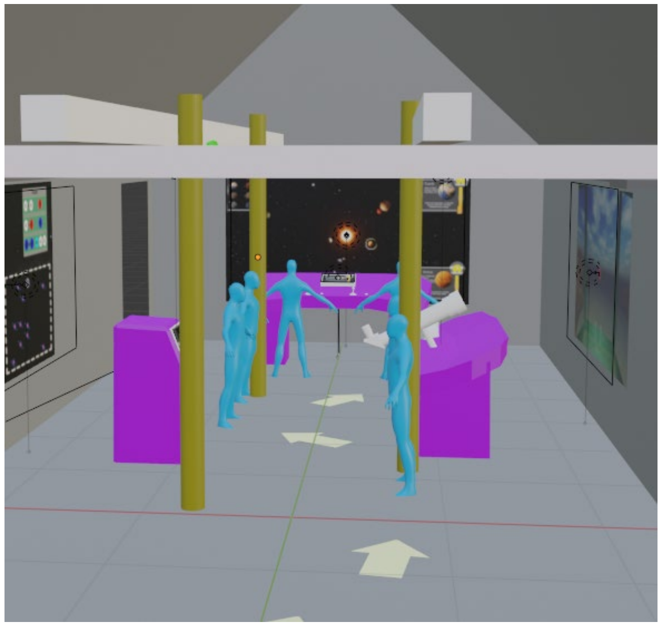


Figure 14: Visualisation of the exhibition room, made by Zario Vries

6.2.3 The frames

Once the concepts of the installations were finalised, the designs went into a state of refinement. Most of the measurements were based on the 3D models present and then adjusted. The most prevalent adjustments were in height and size. According to Molenbroek & Jürgens (1997), the average height of children between the ages of 10 to 15 years old is between 143,3 cm and 170,8 cm. The height of children influences what the components are visible and how the information is displayed visibly for the younger audience.

populations	Dutch Growth 10, mixed		Dutch Growth 15, mixed	
measures	mean	sd	mean	sd
Stature (mm)	1433	65	1708	81

Table 4: Stature of Dutch children between 10 and 15 years old. Molenbroek & Jürgens, 1997

The height of children does not provide all the information necessary to create the installation as the height of children does not exactly explain how high the installation needs to be. Instead, there was a look at what the shoulder depth and reach depth is for children according to the Kima1993 database (Steenbekkers et al., 1993). For Dutch children, there is only data available up to 12 years old. The database lacks the complete range of the age group. Fortunately, the most important data is the minimum height required to reach all components, as making the table too high would make it unreachable, while making the table too small would only generally reduce the comfort of the user. The lowest height that is important to consider is the shoulder height of the lowest person that would visit. The lowest average is found in male children of 10 years old. They have an average shoulder height of 117,5. To include as many of them as possible, the standard deviation was used to calculate where 99% of the users lie in. Assuming normal distribution, around 99% of scores are within 3 standard deviations of the mean. This results in a minimum shoulder height of 99.5 cm which has been calculated by subtracting three times the standard deviation from the mean of the shoulder height of Dutch male children (117.5 - 3x6.0). This means that the maximum height of the installations needs to be lower than the calculated minimum shoulder height to reach it in a more comfortable manner. An estimation of 75 to 90 centimetres was the final height chosen for the installations.

populations	Dutch children 10, female		Dutch children 10, male		Dutch children 10, mixed	
measures	mean	sd	mean	sd	mean	sd
Shoulder height (mm)	1186	61	1175	59	1181	60
Reach depth (mm)	1036	69	1023	69	1030	69

Table 5: Stature, shoulder height and reach depth of children between 10 and 12 years old. Steenbekkers et al., 1993

The other measurement to consider is the reach depth of the person. They should not have to reach too far when using the installation. The smallest reach depth of a 10-year-old female, considering 99% of the users again, is $103{,}6 - 3 \times 0.69$ which translates to a total of 82.9 cm. All the components were placed between the required range vertically and horizontally, unless there was a good reason for it. For example, if space is needed for multiple players to interact with the installation.

Next to accessibility measurements, the blueprints could be developed. The blueprints were made in SolidWorks 2021. During the creation of the blueprints, a material list was made together with a cost picture. The components determine how the frame should be built. The aspects to take care with are the sizes and placement for holes to fit the components and the ways to attach the components to the frame. Some components should for example be attached with screws, others needed bolts or other methods. There needs to be space for all the electronics on the inside of the frame too. This includes the desktop computer. The computer needs to run games made in Unity3D, which requires a bigger model with a graphics card that can handle the games made for it and preferably also more demanding games to future proof the installations. While running the games, the installation will also generate heat, so a hole for ventilation was also considered. As a final point, the frame still needs to be sturdy enough to handle abuse and the weight from the table and people leaning on it. Therefore, the material chosen for the final installation was at least 18 mm thick. 18 mm is one of the thicker standards available and has been confirmed to be a sturdy enough baseline for the installations by woodworkers who will make the final installations. With components, internals and sturdiness in mind, the blueprints could be finalised.

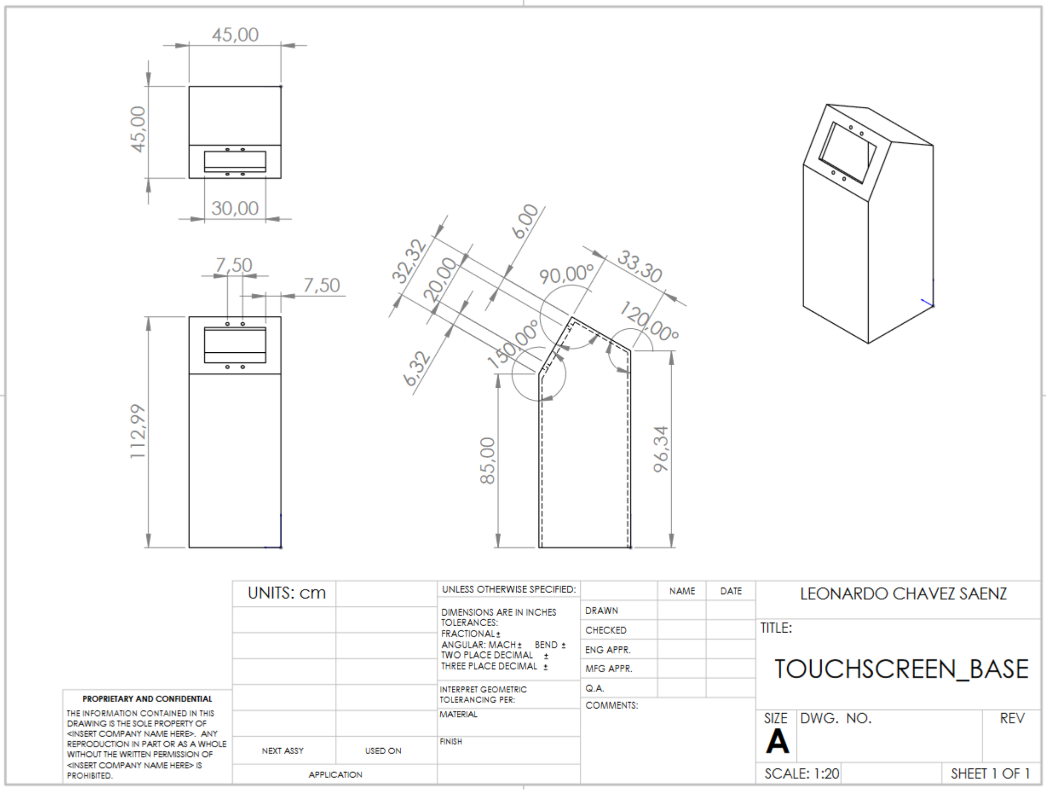


Figure 15: Earlier blueprint of the touchscreen installation.

6.3 Prototyping

6.3.1 First iteration prototypes

The blueprints are the base for making the prototypes. There were multiple prototypes used to test certain aspects of the installations. The first prototypes were for testing the electronics. These were wooden boards where the electrical components like buttons and joystick were put in. They had the same positioning as stated in the blueprints. The electronics were put together using proto cables in solderless breadboards connected to a solderless Arduino. Some of the electronics needed to be tested on functionality and some others more specifically on how to process the inputs.

The biggest pitfalls were the custom inputs, as they always needed to measure non-binary data. One of the inputs is a telescope that can be turned around to move around the scene. The cheapest solution to get this input without any moving parts is using a 3-axis accelerometer and gyroscope module. The result of the testing made it clear that the module needed to be calibrated to the position it was put in and that it was prone to drifting. To solve this problem, three solutions were applied in the software. There was a constant addition applied to set the speed to zero when in a neutral position and a dead zone was applied. A dead zone is a region of input where no inputs are registered. When the telescope is in the neutral position, it will give a value that will fluctuate slightly. This is solved by setting a condition: If the value is smaller than the set boundary, it will give zero back instead. During the testing with the game, it was also found that it was preferable to use the input from the gyroscope, instead of the accelerometer as it does use angular velocity and a compass. This made the telescope close to immune to drifting. By applying these changes, the input from the gyroscope was made to be consistent and processable through the game.

The other big obstacle was the rotating wheel. The wheel is used to 'travel through time' by switching between scenes in the game. The wheel needs to register inputs based on the position it is in. The easiest solution found was to be a colour sensor. It does not contain any mechanical parts, which is important for the durability of the installation. The colour sensor, just like the gyroscope, needs to be calibrated based on the distance from the place where the colours are registered. The colour sensor was tested with coloured sheets of paper. From a software level, the wheel sends key presses to the computer when it detects colour changes. The detection system works in multiple steps. The sensor first constantly checks for the current colour by converting the data to RGB values. If the colour changes between cycles, it will check if the next colour registered is still the same to confirm it is not a faulty measurement. Finally, the code will check if the colour is close to one of the colours hard coded in the software. It will then send the appropriate signal with the colour it viewed as a number on the keyboard.

At this point in time the games were not able to be properly tested as the inputs from the games were not ready for the hardware. When building installations where the software is made parallel with the hardware, communication is key. No assumptions should be made from either side. The lack of communication between departments was clearly prevalent in this project, as remaking some of the controls would deem to require more work. The game integration would need to be tested at a later stage.

6.3.2 Final iteration prototypes

The final iteration of the prototypes was more detailed. They were real scale models of the final installations. With these prototypes, the height, size, and positioning can be tested. To make these, a wooden structure out of beams is made where wooden multiplex panels are attached to. The panels were 10 mm thick, so they could be laser cut. To save time, the two table installations used the same frame with a modular top that could be swapped out with the other one. This prototype can be seen in figure 16. In the new prototypes, the electronics from the first iteration of prototypes were placed to test them in a more natural way. The result was that the tables should be lowered slightly and that the angle of the screen for the touchscreen was better reachable in a more vertical position for children, as the light would reflect on the screen if in a 45-degree angle and be less visible. On the other hand, it would be too low for adults to see if placed at too low of an angle. The result is a good compromise of height and angles, where every person could see the installation, but the comfort for usability was favoured towards the main demographic of 10 to 15 years old.

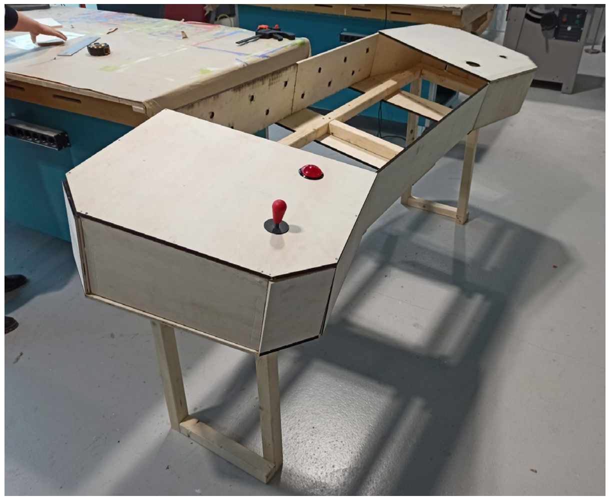


Figure 16: Final iteration of one of the prototypes. Enschede 2021

6.3.3 Pitfalls and improvement

One of the biggest pitfalls encountered during the building of the prototype was the custom components for the third installation. The telescope and the wheel revealed several potential issues that had to be solved. The telescope has multiple mechanical moving parts. This means that the telescope was the most complex to design and it could be prone to breaking. The design evolved by making the telescope rotate on two axes. It can rotate left and right using the round beam that serves as the mount for the telescope. The beam attaches the main body to the 'optical tube' of the telescope. The other axis turns using a bar through the middle of the telescope. The bar is attached on both sides of the telescope to the mount. Both bars for the axes had to be invisible in the final installation as unnecessary moving parts should be hidden for the user.

The coloured wheel used for time travelling also has certain roadblocks that came up when testing. The wheel needed to be adjusted on the amount of drag needed. If the wheel spins freely it can potentially go too fast and harm the users. For the same reason, the gap between the wheel and the top of the installation needs to be as small as possible, to not get any fingers stuck in there. A smaller gap between the wheel and the table also limits the amount of light that disturbs the light sensor.

When building the later installations, these potential issues can be avoided through encountering them early. Also, the designer can look if the problem should be solved, or a new way of input should be considered.

6.4 Feedback on prototypes

The prototypes and their blueprints were viewed and casually used by multiple people. During the construction phase feedback was received, which gave more insights in certain areas that were not accounted for in the design. There was feedback from the software engineers at GameLab Oost considering the integration with the game. Other feedback was given by the clients from Cosmos Observatory and a professional industrial designer.

Installation one is a game about controlling a spaceship to explore the solar system. It is controlled by a 2 directional joystick which turns the ship left or right. To improve the controls, the installation will instead use a four directional joystick to have more options and change the gameplay to be more fluid. The size of the buttons was also deemed important, as it should be child friendly for their motor skills and pressing abilities. The buttons for the final prototypes all have a cross section of 6 cm with little resistance, so it is easy to click. Another important aspect that was not taken into consideration yet, was how the screen would be attached to the frame of the final installation. The blueprints were altered according to the 100mm VESA mounting brackets that could be included in the mounting process.

Installation two is about the inner process of the sun, done through a touchscreen. As with the first installation, the touchscreen needed to be better prepared to be mounted. This installation is less stable because of the smaller surface area that the bottom covers. This sparked into a conversation about anchoring the installation to the ground for less accidents. How this is implemented, is seen later in the realisation. On a software level, the game needed to be better playable as it was difficult to aim the moving atoms on the screen. It needed slower movement and bigger hitboxes to feel more lenient and responsive.

Installation three is the table where the user time travels to different scenes in the past and future. In there, the player finds points of interest to learn about the environment. The feedback on this installation was rather divisive as the form factor was rather unique. From the software team’s perspective, the connection with the game could have been stronger, while from outside of the developers, the reactions were more affirmative as the telescope encompasses the urge to play very well. As there was limited time for designing further, the form factor remained relatively the same concerning this feedback. Other feedback included potential risks with loose hanging cables and restricting the angle of rotation so that children could not break it. There were also missing measurements in the blueprints which were fixed afterwards. The result was a safer, more complete design for the custom components.

In conclusion, the designs received a positive reception with some small improvements that had to be made. The installations have been fine tuned to be safer, ergonomic, and more immersive with the games. One final advice was to look at the guidelines for playground equipment in public space and the commodities act decree on amusement and play equipment according to the Netherlands. In there, there is a list of safety measures that are needed for the final designs including safety, maintenance and considering how the device will be used from different perspectives. This was useful to consider while the final design was made. Now that the designs are polished enough, the final installations could be constructed.

Chapter 7 - Realisation

The final designs are now complete and will need to be realised into a final product that can be put into the Cosmos Observatory. The production was completed together with multiple professionals in their respective fields to create a satisfying result. The production encompasses the different aspects that the installations are made of, namely the hardware, software, and the frames to fit the technology in. Together they resulted in a complete product that can be interacted with for a long time, as it was placed in an exhibition hall, modelled to be an immersive environment with space to interact with the installations together.

7.1 Building of the frames

The final installations were made together with woodworkers from Artez / AKI in Enschede. This meant that the previous blueprints needed to be adjusted and have extra information so that the integration of certain components would go fluidly. For that a design document was set up with specifications about the designs. It contained information about design choices, what would go in the installation and how it would fit. During the development process, some problems were encountered considering miscommunication and wrong measurements. This had to be corrected within the time frame of the building.

The final installations were made from thick MDF plates with a white lacquer carrier foil. This was chosen as no internal frame would be needed anymore and it would have a sturdy smooth surface on the outside. The sides of the panels had visible marks where the wood was sanded down, so a new coat of white paint was applied on the sides. The colour wheel would also get a paint job simultaneously. Because the final installations used a thicker material, the screens would need to be attached differently, which was not accounted for. This was solved by providing the screens physically and discussing the different attachment methods available. Another important point was that the desktop computers needed to fit into the legs of the table installations. These legs were designed to be just big enough to hold them, but the size of the cables sticking out was not accounted for. The thick legs also needed to be ventilated, but they had no holes for this. The solution for both problems was to cut out big holes in the back where 3D-printed ventilation grilles would come. This provided the necessary airflow from the computers to the outside and gave some more space in the legs to manage the cables.

7.2 Integration of electronics

After the frames were finished from the woodworker's perspective, the electronics were carried over from the prototypes into the final installations. The integration was done together with [13]AcE Craft. There were already some holes available for cabling, while some others were missing. These were drilled first. The electronics could now be moved. The first installation contained joysticks which are normally screwed in from the bottom. However, there was no easy access to it and to solve this issue there were holes drilled into the top of the installation. In general, having visible components at the top is highly discouraged as visitors could see and get to it. Invisibility is important, but access for attaching the joysticks has equal importance, for later emergency maintenance. With the holes made, nuts and bolts could go through to firmly attach the joysticks. The buttons were easier as they had an easy system to screw them in and more space to work with.

All the electronics were removed from the breadboard to instead be soldered to circuit boards. Soldering results in a more reliable and permanent solution where contact between the components is better and less easy to break. Some components like the Arduino itself were not soldered in the end as they had their own brackets to put the cables in. Removing these brackets would cost time that was not available at that moment. After soldering the cables and the components together, all the electrical components were put together. For the cable management, different coloured cables were used. In general, red is used for the input voltage, while black is used for the output. Other cables should preferably be differently coloured. Because of the limited colours available, this was not always possible, which led to some later integration issues. The cables were cable managed with rip-ties which are placed in small brackets screwed in the top of the installation.

Figure 17: The integration of the telescope

For the Custom components, the sensors needed custom mounting brackets to integrate them invisibly into the installation. The colour wheel had a T-shaped attachment to measure the wheel from the centre of the side and the telescope needed the sensor integrated through the side. A custom casing was designed and 3D-printed at the side of the telescope where the sensor resides. The cables would ideally not be present on the outside as seen in the research. A possible solution to the problem would be to make grooves in the wood and use conductive rotating joints for the connections between parts, but this was considered too complicated for the remaining time frame. Therefore, the alternative solution was to lead the cables through the outside of the telescope through thick industrial cables. In the end it makes for a cheap solution which gives more of a ‘spaceship’ feeling through its look.

After the cables were placed the electronics were tested by running the Arduino software, which sees the signals that come in through the Arduino serial monitor. According to the results, the cables had to be reorganised or checked for connections. The cables could be checked through a multimeter. A multimeter is a measuring instrument that can measure multiple electrical properties. According to the results some cables had to be re-soldered before finally finishing.

7.3 Game integration

Before the installations could be deemed finished, they needed to be tested with the games. The final games have been tested before with the hardware but had gone through further development in the meantime. In the meantime, the hardware also underwent minor changes that were made to integrate better with the new builds of the games. Only once all these changes were tested, it could be declared done.

The first table had incorrect controls for the joysticks. This was fixed together with the new controls for four directional inputs in the Arduino software. The test went successful with the game running as expected. The touchscreen installation was integrated easier, as it requires no extra configuration of electronics. The only important configuration that had to be done was to turn off touch specific motions in Windows 11, as they are on by default. With the touch motions on, you would be able to swipe the game away and right click on the screen, which should not be features available for the end user. Finally, the table with the custom components required the most work. The colour wheel needed calibration for each range of RGB values. Afterwards, the Unity software needed adaptation from the software team's side for the exact way the inputs are transmitted into the game. Originally the time travelling in the third installation was done by moving the colour wheel to an exact colour to go to a corresponding scene. The new version of the game relies on moving the wheel forward and backwards instead. This way of integration was deemed more immersive, as you move forward in time by moving the wheel forward. The integration was also more understandable for the user, as no positions needed to be remembered from the wheel. From the software perspective, it makes it easier to change the game to have any arbitrary number of scenes in the game.

7.4 Final placement in Cosmos

When the installations were finished, they needed to be transported to their final location at Cosmos Observatory Lattrop. Once there, a couple of things needed to happen to complete the installation of the consoles. The consoles needed to be put into the general space. When in the specification phase, there were some considerations on how the installations should be placed. The position of the installations was decided based on the visitor flow in the room. The goal was to create an inviting open environment where you can see all the installations and where visitors have space to move around. Installation one (the arcade table) was placed in the back as the centrepiece of the room. Installation two (the touchscreen) was placed at the right front of the room. Installation three was placed in the left centre of the room. The positions of the installations resulted in a flow from right, to left, and finally to centre, while still being able to pass other people if they were busy with one of the installations.

Figure 18: The exhibition setup at Cosmos Observatory Lattrop 2022

The beamers needed to be placed in a position where people cannot interfere with the visibility of the screen. There were two short throw beamers for the left and right walls, while there was one normal beamer for the wall in the back. The beamers were placed on top of the crossbar supporting the building. The installations were placed at roughly 1,5 metres distance to not interfere with the projection and give enough space for the image to be visible to the rest of the crowd. To complete the installations, stickers were placed at the surface of each installation. The stickers were designed by a visual artist contracted by GameLab Oost. The designs were made more abstract and fit with the white aesthetic of the rest of the table. Adding a final visual touch gives multiple benefits to the installation that are often overlooked. It attracts people to play with the installation and increase the opinion of people playing the installation, no matter if there are flaws present in certain parts of the design (Schell, 2020). The visual design also leads the eyes of the user in the right direction, indicating important parts in the interaction. With the final visual touch, the installations are complete.

Chapter 8 - Evaluation

The installations were completed at this stage. That means that they could be tested to see how much aligns with the research done up until this point. The installations had several areas of interest which were considered while making them. These were subjects like the use of physical interactions over virtual ones, the balance of usability through a simple and understandable design or the importance of a social experience. It is possible to check off some parts that are included in the design, like seeing that the installation is sturdy or contains the possibility for multiplayer. That does not mean that it is guaranteed to improve the experience of the end-user. Subjectivity is a core element of making a creative design. Design can invoke different feelings in different people. What is important in this project, is that the general audience of Cosmos experiences the things that the designers intended. This was measured through user-based testing.

8.1 Participants

Ideally, the test is done with a variety of people, where the main demographic is the most important to test with. In the case of this project the target audience is 10 to 15 years old. Multiple schools were contacted and scheduled for tests. However, some complications showed up, making this impossible. The most suitable alternative that was found was the recruitment of a variety of people of different ages and backgrounds outside of schools. The upside of this recruitment is that the people could have a bigger variety of backgrounds, as can be found in a real-life scenario. Other people with, for example, disabilities could also be recruited easier without the constraints of a school. The downside is that a lack of people in the target population is recruited. The alternative testing method was finally chosen and deemed adequate to gather useful results for this report.

Participants ($n = 8$) were recruited through personal verbal contact, via phone calls, or social media messages. The participants ranged in age from 18 to 60. No other information was recorded as the test was done anonymously. Participants of both genders equally were present. One person was present in a wheelchair.

8.2 Testing methods

To analyse the topics around the research, a set of testing methods were applied. While the participants play with the installations, researchers will apply the 'Thinking aloud' method to gather more information. Nielsen (2012) describes the method as follows: "In a thinking aloud test, you ask test participants to use the system while continuously thinking out loud — that is, simply verbalizing their thoughts as they move through the user interface". The method was chosen because it adds more information behind the participants' actions that can otherwise not easily be found. While the thinking aloud method happens, the researchers can also note down observations of the users interacting with the installations. This is to ensure the underlying actions of the user are not influenced by the commentary of the researcher and to enrich the knowledge learned while the interaction happens. Users tend to perform actions subconsciously and these subconscious interactions can be found clearer through observations.

At the end of testing an installation, the participants could fill in a questionnaire. The questionnaire was chosen to measure different dimensions of the research. Each dimension was based on one or more topics of interest for the research. The questions were based on existing HCI-based questionnaires from Moreno et al. (2016) and Norman (2010). These research reports use questions with different dimensions concerning gaming engagement and immersion. In Moreno's (2016) attempt to evaluate their interactive installation, they used 4 dimensions: Enjoyment, Immersion, Gameplay and Enjoyment of game elements. Next, they have 2 other categories: Balance/fairness and Skill level. From this questionnaire, 7 questions were chosen around enjoyment, immersion, and gameplay. Other elements were not chosen, as this research is more focused on the custom controller experience, than on the gameplay. Norman (2010) created a "Post Game and ImmersiveNess Questionnaire" based on different factors of immersion. From this questionnaire, 5 questions were chosen. Some questions were repeated twice. One was to measure the results for the custom controller installation and the other one to measure for the classic controller.

The resulting dimensions of the questionnaire were 'Immersion', 'Usability', 'Accessibility' and 'Social engagement'. The questions from immersion and usability were taken straight from the pre-existing questionnaires. As the installations are different from other games, some questions were converted to usability. Usability encompasses questions around 'gameplay', and 'sense of control'. 'Accessibility' and 'Social engagement' questions were not present in the existing questionnaires and served a different purpose for this research. Accessibility questions ensured that the quality of the product was ensured, through seeing if the chosen height and reach depth were alright. Social engagement on the other hand is simply not present in the chosen questionnaires. Instead, these are self-made questions that go over different parts of social interaction in the background research, namely Cooperative gameplay (Hadjakos et al. 2015; Schell, 2020), Space for commentary (Hornecker & Stifter, 2006; Hadjakos et al. 2015; Pisoni et al., 2021), Performance for the crowd (Hornecker & Stifter, 2006), and Easy handover (Hornecker & Stifter, 2006; Hadjakos et al. 2015). In the questionnaire six questions were made based on social engagement. Five of these questions were asked for both the custom controller and the classic controller.

The questionnaire had a total of 32 questions split into two sections. Section one was about Accessibility' and 'Social engagement'. Section two was about 'Immersion' and 'Usability'. The questions used a Likert scale which ranged from 1 (Strongly disagree) to 5 (Strongly Agree). The likert scale was chosen for later analysis of the results. The scale was not made too big, in case children participated. All the questions were reviewed by the project supervisor from the university before being accepted. The questions with their dimensions and sources can be found in appendix G. The final questionnaire can be found in appendix H.

8.3 Procedure of the user-test

As the installations were put in the museum the test could take place in their natural environment. The test was planned out at a time that the museum was officially closed, which gave more liberty in terms of time, space. The freedom also made sure that the participants did not have too much external stress or other extraneous variables while playing with the installations.

Before the test, the participants got a short introduction explaining to them the testing procedure and the thinking aloud method. Once the test started, the participants were going to play with all 3 of the installations, one at a time. Next to each installation was a setup for playing the same game on a computer with an Xbox controller (for Xbox One / Series S/X). The purpose of testing the games twice is to see the possible advantages of the installations compared to traditional controllers. According to the background research, the installations should bring a better museum experience. The games were prepared beforehand to be playable with both the traditional and the custom controller.

The games were played in pairs of two. This served two purposes. The first was to engage more participants simultaneously, and therefore get more results over a shorter period. The second was to test the social aspects of the interactive installations. The importance of social interaction was highlighted multiple times in the background research (Hadjakos et al., 2015; Hornecker & Stifter, 2006; Müller et al., 2010; Pisoni et al.,2021; Schell, 2020). All three installations use their social aspect in different ways, so testing in pairs should provide meaningful insights.

Next to each installation, there was a researcher present. This meant that any researcher would overview two people at a time. During the test, the participants would freely play with the installations while the researchers could write their observations and encourage the participant to use the thinking aloud method. The researchers could guide the participants if needed in their gameplay or their thinking to remain within the testing goals. To accomplish this, the Wizard of Oz method could be used if deemed necessary, where the researcher could manipulate the installation from a distance to simulate what the installation is supposed to do. Once the participants were ready with playing one of the installations, they could fill in questionnaires based on their experience with the installations. Then they would proceed to the next installation. Once all installations were played, the test was finished. In the end almost every pair of participants had the opportunity to play with all the six setups and filled in all the questionnaires.

8.5 Results

During the test, there were 6 setups where 8 participants played with. The results are presented in two forms. First, the test had a questionnaire with quantitative questions on a Likert scale of 1 to 5. The scaled data could be used for making multiple statistical analyses. The second form of information gathered was written commentary about how the participants felt when they played with the different setups. Paired with the remarks and other observations, this gives a more complete overview of general comments and if the installations accomplished their goals.

8.5.1 Statistical analyses

From the questionnaires, data was processed to check whether the results from the background research aligns with the findings in this project. Like the literature research, the sub-questions are used to create the analyses of the questionnaire data. As a reminder the following are the research sub-questions:

1. *What is the most important when enriching the engagement in a museum?*
2. *How can serious gaming installations balance the edutainment present within the game?*
3. *What benefits do custom controllers have compared to traditional ones?*

The first analysis done is measuring if the benefits found from the custom controllers are indeed higher than the ones from a traditional controller. During the test, there were measurements for immersion and (social) engagement for both the traditional and custom controllers. The results of the measurements found that on average, the immersion and the engagement were slightly higher for the custom controllers.

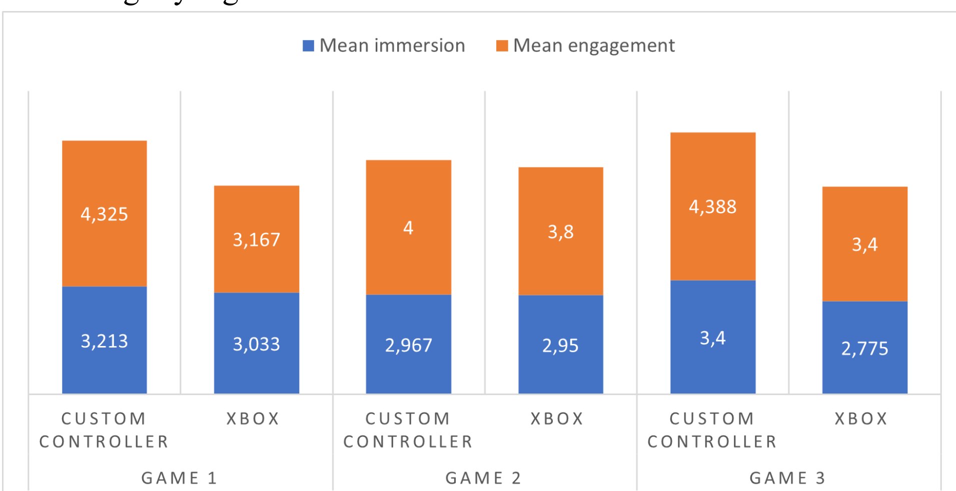


Figure 19: The mean scores of the custom controller installations versus the Xbox setup.

To ensure that the difference in these results is statistically significant, an analysis of variance (one-way ANOVA) was done for each installation. In the analysis, the statistical difference was tested between the two versions of playing the game. The null hypothesis H_0 is that both the Xbox controller and the custom controller have equal value based on immersion and engagement. For ANOVA, the F-score is calculated based on the results of 10 questions answered by the 8 participants. In the following example, the processing of the data from game 1 (Solar system exploration / arcade table) is explained. As some people did not manage to play all 6 games during the test, there is a slight difference in the number of answers.

Group	Questions	Number of Answers	Mean	Sum of squares within (SSW)	Sum of squares between (SSB)	Sum of squares total (SST)
Custom	10	80	3,76875	140,471875	6,571492	
Xbox	10	60	3,1	95,4	8,761990	
Total	20	140	3,482143	235,871875	15,333482	251,205357

Table 6: Calculating the SS values of game 1

n	Groups (g)	df_{SSB} (g - 1)	df_{SSW} (n - g)	SSW	SSB	MSB	MSW	*F*
140	2	1	138	235,871	15,3334	15,3334	1,70921	8,97105

Table 7: Calculating the F-value of game 1

With the F-score, you can find the p-value which gives the result of the analysis. When taking a standard significance level $\alpha = 0.05$, the result is $p = 0.0065$. This makes the result statistically significant and therefore we can conclude that in this test, the custom controller for game 1 had a significant benefit compared to the traditional controllers.

The results for game 2 (The touchscreen installation with sun processes) concluded that the null hypothesis could not be rejected. This means that the touchscreen controller did not seem to be significantly more immersive or engaging than the Xbox controller. This also aligns with some of the literature research where touch screens were often not seen to be preferred over physical hardware components (McIntyre, 2009; Hornecker & Stifter, 2006). The third installation (time travel table / Sun and Earth relationship) did seem to reject the null hypothesis and therefore is also significantly more immersive and engaging. Overall, the custom installations proved to have a statistically significant positive effect on the user experience. Physical interactions were indeed preferred over touchscreens or traditional inputs.

In previous research several topics of interest were found that were explored in the building of the installation. During the test, the questions were set up specifically to test these dimensions of the installations. They were measured by taking the average of the participants and then also averaging the different questions within dimensions. The results are displayed in figure 20 below.

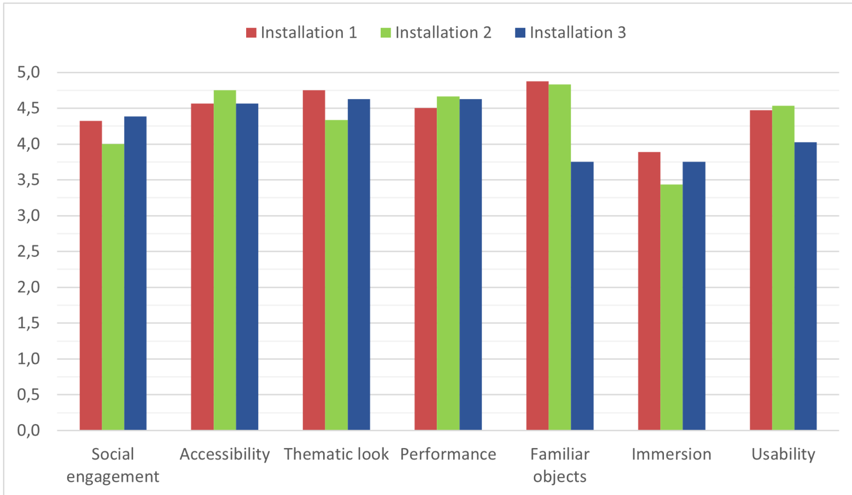


Figure 20: Different dimensions measured during the playtest

In general lines, the installations seemed to score relatively similar. The accessibility and physical performance factor of all installations seemed to be about the same for all of them, while other factors like familiarity seemed to contain clearer differences. This is partially attributed to the number of questions per dimension.

Installation 1 (solar system exploration) was found to be the most thematically fitting and was easily recognised. Installation 2 (sun processes) on the other hand was the most accessible and user friendly, probably through the clear interaction that matches the game. The third installation seemed to be less easy to grasp and the users had some problems when first interacting with the installation. This is also found in the statistics as the level of familiarity and usability were lower. On the other hand, the performance factor and the social engagement seemed relatively high, definitely considering the game was the least optimised for the installation and the fact that the installation isn't made to be strictly a two-player interaction.

When merging the results, the overall scores are found for the exhibition. The scores are merged by taking the averages of all people and afterwards averaging the results of the questions that have the same dimension. The scores are calculated on a scale from 1 to 5. The overall experience based on the questionnaire measured at a 4,364 out of 5. Thanks to several considerations when designing the installations, like measuring the height and the considerations for wheelchair users, the accessibility stood out the most.

Something curious is that the thematic look is a precondition for immersion as the appearance for the installations should change how the user immerses in the game. Other factors might be the reason that the immersion is lower than expected. One reason visible in the results can be attributed to certain reversed questions, where the opposite of immersion is insinuated. The results are then flipped when processed from one to five and the other way around. One of the reversed statements was "I was aware of events occurring in the real world around me using the installation". The idea behind this statement is that people who are immersed in the game do not see what is happening in real life. The problem is that the physical installations are part of the experience and not only a means to play the game. Therefore, the physical installation also takes away some attention. Having people focussing on the installation can be considered positive, so this will be further explained in the observations.

Dimension	**Score**
Social engagement	4,238
Accessibility	4,625
Thematic look	4,569
Performance	4,597
Familiar objects	4,486
Immersion	3,690
Usability	4,345

Table 8: resulting measurements for the exhibit per research dimension

8.5.2 Observations and remarks

During the test, three methods were used to collect qualitative written data about how the users felt using the installations. These three methods were standard observation from a distance, thinking aloud and a remarks section in the questionnaire where the users could give a conclusion after the test.

In the remarks several improvements for the game were suggested from the test participants. Suggestions from the user's side can be very powerful, as they see the installation from another perspective. As a designer, there is a deeper understanding of how one's own design can be handled. A designer also tests their prototypes more frequently, to the point that it becomes very natural for them to handle the normally less intuitive interactions. On the other hand, the designer should consider that the user is not always right. Schell (2020) describes this issue as the 'innovator's dilemma'. Often, new technology is not yet good enough to replace the old one. This is also found in this project, as during the test the custom component installation was found to be the most clunky and in need of improvement. Making future improvements seemed to be critical to this installation as it has the most potential to rise above the others in terms of immersion and engagement.

The first installation was considered the most ‘game-like’ as the controls gave a feeling of playing a game. The game was very intuitive, and the participants did not need a lot of time to figure out what to do. This game feeling made the people feel challenged and sparked a level of competition between the participants. Several individuals gave suggestions on making interaction between players in the game possible, which can be seen as positive as this indeed means that the social aspect is present and is wished to be improved even further. Another recurring suggestion was making the planets explorable as individual checklists instead of one checklist for both players, to increase the level of competition even further. This could be counter-intuitive for the goal of the installation though, as the learning goals were often not met, and the installation self was not explored much physically. The second screen in the middle was often not seen until the end of the game. This is partially because of the prototype of the game, which does not encourage exploring it. The other part is because the players used the joystick very intuitively and were not encouraged to move around with this installation. One point that was made for this installation was that it could refine the wheelchair accessibility. While the game is perfectly playable, the player area is placed right in front of the leg. This made the wheelchair user almost bump into the leg.

The second installation with the touchscreen was considered very intuitive to play. The swiping of atoms was clear from the start for most users. As seen with Long et al. (2019), there was an initial phase of engagement where the participants started exploration through one component, which was the standard interaction of merging atoms. The problem was that users seemed to swipe them at random and about half of the people still were not sure if what they did was right or not. The other half that took their time and did understand the interaction, achieved the learning goals as they were discussing what atoms needed to be fused next. The fact was that no negative consequence was present. This seemed to impact this problem, as participants could brute force the interaction to speed through the game.

The third installation had some of the most interesting observations. While it was not clear from the statistics, there was a lot of divisive commentary about the installation. Some important remarks that several users made was about how the telescope handles. In this part of the test, the Xbox controller was considered easier to use than the installation. The custom controls were not smooth enough and the dead zone where no inputs were possible was stated to be too big. A lot of participants seemed to struggle with handling the interaction. This is partially because of the lack of refinement for this interaction and partially by design. The game in general is more exploratory than the other two games. There was close to no challenge present in the gameplay and instead the focus was on interacting with the installation. What was not accounted for was that this would provide an extra challenge. Some users found the interaction with the telescope to be the main ‘fun’ part of the whole interaction as they had to navigate through the level. This gave some users “the feeling of being a researcher” as quoted from one group of participants. When testing with the traditional controller, the game went way faster, but the learning goals were not achieved, and the enjoyment of the game seemed to be lower.

The colour wheel on the other hand had more neutral commentary, where some users did not understand how it worked completely at the start, making some participants go through the end scenes way too fast. This caused some confusion, but also amazement, as their actions changed things. In the end, the interest curve for this installation seemed to be more adequate and more learning goals were met. The text on the screen was also read more. From the information available, it seems that the required focus on the installation helped the user take time to read when paying attention to the screen. The fact that knowledge is the ‘reward’ for the player also helped in this.

In total, three installations were made and tested. The participants had an overall enjoyable experience. The gameplay and installation influenced the amount of knowledge gained during playing the games. There were also some points of improvement for both the hardware and the game.

Chapter 9 - Discussion

The design

Design is partially subjective just like the preferred techniques used in the design. This research is specifically focussed on custom controllers but does not go over all the aspects of making an installation. The software and games that are used for the installations have their own foundation and theory in game design and HCI (Human Computer Interaction). However, the software is an integral part of the installation. The designer can take the aspects found in this research into account when designing the software for serious games. There are also a variety of other principles that have not been completely covered in this research, due to the time restraints of the research phase. Some examples in psychology and design are the principles of Behaviour Change Techniques (BCT) and UI/UX design. These principles can provide more insights if needed for the design of specific behaviour guidance and interactions.

Each project is unique and therefore can require the designer to prioritise what is the most important according to their time, space, freedom of choice and budget. Some projects, for example, do not have the time to do extended user testing, as was seen in the interview with 100%FAT. Other projects might have stricter guidelines, where the designer needs to convince the client of their choices and so on. Thanks to the interaction with the visitors, the museums can learn from the input of the public. The museum design should be flexible and open-minded to improve their interaction with the public. Custom controllers can be a great source to achieve a better museum visit experience. Custom controllers have possibilities to grow, as research on this topic can still be improved upon.

In general, custom controller installations seem to have positive results for a museum and can enrich the experience in numerous ways. That does not mean they are flawless or contain negative aspects to them. Poorly designed installations are double edged swords which could harm the user experience. They could make the installation harder to use and distract from the game to an unhealthy extent. Interactive installations require time to balance and are more costly than a traditional computer.

What is more, is that custom controllers are hard to be reused for other games. Museums want to evolve continuously, and custom controllers might need to be replaced sometimes. As is stated in the name, custom controllers are customised for a certain experience. Custom controllers are possibly not ideal for other new experiences unless those experiences are designed with the inputs in mind. As a designer it is recommended to keep these things in mind, when making a custom controller installation or making a game for it.

Problems and limitations

In this project, three installations were developed, which is more than average for a graduation project this size. A lot was accomplished, but also some problems showed up and some corners were cut to ensure that deadlines were met. During the project, the clients were continuously involved in the design process. This was done based on 100%FAT, who sees the communication with the client as a top priority that needs more attention. Even though the clients were involved during the whole process, some miscommunications still happened. The biggest recurring problems were deciding on the scope of the project and the integration with the hardware. These are points that should be tackled early in the project. Any parties developing games for installations need to be aware about the integration of the software in the hardware and both the designers of the games and installations need to understand the importance of making the experience elevating each other.

The Specification and Evaluation phase were affected the most from the limitations of the project in terms of time and resources. In the specification, there was only a limited number of prototypes made. The prototypes that were made could have been more simplistic and effective through lo-fi prototyping and tests using the Wizard of Oz method. In this hypothetical test, the inputs of the participants could have been tested by letting the researcher register the inputs from a distance with a keyboard and mouse. This could have spared time and given opportunities to make more iterations on the prototypes.

The evaluation test encountered some difficulties as the playtest was originally planned to be done with the target audience of 10 - 15 years old. Testing with children requires careful consideration of the ethics and needs a lot of planning. Depending on the age, different forms of consent are needed. Multiple schools were contacted for this research and tests were scheduled, but the playtests got cancelled due to multiple reasons. In future endeavours, there should be more tests with a bigger group for more valuable results and the arrangements and consent should be handled months prior.

The playtest itself went relatively well, with all participants willing to play all installations and fill in the questionnaires. At the start of the test, an introduction was given about what was going to happen during the playtest. After the introduction, they started playing. What was clear rather quickly was that the test participants gave a lot of commentary strictly about the game instead of the installations. In future tests, it is important that the wanted data should be explained clearly to both the researchers and the participants, so that the results are more valuable.

After the test was a questionnaire for the participants to fill in. There are a couple of improvements that the questionnaire could get. First, the test contained a part where immersion and social engagement is compared between the custom controller and the traditional controller. In this part of the test, more dimensions could be explored. Most notably the usability of the installation. Next, there could be more questions per dimension. Some dimensions had one or two questions, which made the results less reliable. Ideally each dimension would have 5 questions, but there are certain considerations that should be made. The current questionnaire has 32 questions. If this were increased, better conclusions could be made, but at the cost of the participants wanting to fill it in. Filling in three questionnaires (one per installation) is already quite time consuming. In a smaller test with adults (like the one in this research), this forms less of a problem and can be done if considered fitting. If a future test is done with children, filling in so many questions cannot be expected. It could negatively impact the results. Therefore, sacrifices might need to be made anyway by considering which dimension is the most important to test.

Future Work and recommendations

The three installations for Cosmos Observatory Lattrop are at the time of writing set up in their exhibition. While these installations are considered 'final', they can still be improved upon. The games can and still are improved, even after the end of this project. They should try to fully utilise the installations for more engagement and to improve the learning gains of the games. The users should get the time to explore without trying to reach a goal as fast as possible. The hardware can also be improved already, with some smaller adjustments. The colour wheel of the custom component installation is designed to be adjustable in how hard it can spin. This can for example still be optimised to be usable for people with muscle weakness, while not spinning so fast as to harm children who play with it. The telescope can also improve in safety by limiting the angles the telescope can be put in. The usability on the other hand can be improved by adjusting the dead zone and movement speed.

Custom controller installations are valuable options for a museum and require more research to solidify what important benefits they can achieve. In this research, some aspects were explored, but they could be tested more thoroughly through bigger tests. The fact is that these installations were made for children to interact with, but there was no test possible to see any insights from children compared to the adult audience. The benefits and requirements for children specifically have much potential to elevate the museum experience and the experience in other public spaces with children. Another part that can be explored further is the use of physical activity and sensory engagement in a museum setting. From the limited research made in this project, these factors seem to have positive effects, but would need to be researched in more targeted research.

The next step that Cosmos Observatory and GameLab Oost is currently taking is the development of a more portable, universal interactive installation. This installation is being developed for [14]Expedition NEXT. In their quest, research around developing more universal installations for games could provide valuable findings to compare to custom controllers made for specific games.

Chapter 10 - Conclusion

At the start of the project, there was an urge found for innovating a museum through custom controller installations. The research setup for this aimed to explore the research question "*How can custom controller installations improve serious games for visitors of a museum exhibition?*". To accomplish this goal, background research was done based on three sub-questions: "*What is the most important when enriching the engagement in a museum?", "How can serious gaming installations balance the edutainment present within the game?" and "What benefits do custom controllers have compared to traditional ones?"*.

The background research resulted in a set of topics of interest used in the rest of the research. These were: 'Physical interactions', 'Usability', 'Sensory experience', 'Immersion', 'Familiarity', 'Accessibility', 'Sturdy and Invisible hardware', 'Social experience', 'Visibility' and 'Thematic and Innovative appearance'. These topics were implemented into the design in four phases according to a co-creation design process based on the Creative Technology Design Process. After implementing several iterations of prototypes, three designs for installations were created, each having a unique design and game. The first installation explored the solar system through an arcade-style game where you fly from planet to planet. The second installation explores the workings of the sun by swiping atoms together to create nuclear fusion. The third and last installation teaches the user about the lifecycle of the sun and how it affects the earth. This is done by travelling through time and exploring the scene through an installation with custom components, namely a telescope to look around the scene and a wheel to scroll through time.

After prototypes were made to find improvements and refinements, final installations were constructed. With the final installations, the topics of interest from the background research were tested, with a focus on Immersion, Usability, and the Social Experience. Other topics were also tested to a lesser extent. In the evaluation, a small group of people freely experimented with the installations in a playtest. The results were recorded using thinking aloud, observation, and a questionnaire. The questionnaire contained quantitative questions using a Likert scale. The quantitative results were processed using statistics and ANOVA. The qualitative results were used to base other conclusions on.

Returning to the research questions, a conclusion was first made on each of the sub-question, which in turn answers the main research question. Below the answers are presented.

"*What is the most important when enriching the engagement in a museum?*"

In the museum, people engage with installations in two ways: passively or actively. The passive experience focuses on the overall visibility and social aspects. The exhibit should be an inviting, open space with a clear overview of all the installations or attractions. When the user enters, seeing other users play can attract them to actively engage. This is done the best if the installation requires the user to perform physical actions for others to see.

The active engagement starts when people give inputs to the installations. First the user needs to be attracted to engage. People will want to engage with installations when they have an innovative and attractive appearance. Using familiar items can help lower the entrance into the physical engagement. To keep the user engaged over time, there needs to be a feeling of exploration and a fitting challenge level that adjusts over time.

"How can serious gaming installations balance the edutainment present within the game?"

When considering making an installation it is important to balance the inputs. Inputs that feel too natural or too smooth will make the user move too fast through the game. If this is balanced through an increased challenge level, the focus will lean too much on the challenge instead of the learning gains. On the other hand, if the interaction is too clunky, the experience of the game can be hurt.

If interactions were considered before acting, more learning happened. The user needs time and space to reach the learning goals. Making a balance of complexity of inputs together with physical movement seems to be the preferred way to achieve the learning goals within the game while also enjoying the experience.

"What benefits do custom controllers have compared to traditional ones?".

On a level of immersion and social engagement, custom controllers seem to have more value than traditional controllers like mouse and key inputs, Xbox controllers or touchscreens. Custom controllers provide the opportunity for physical activity and are in general considered more fitting in a museum setting than their traditional counterparts. As is seen in the touchscreen installation, traditional controllers can still be both more and less fitting interaction depending on the situation.

"*How can custom controller installations improve serious games for visitors of a museum exhibition?"*

Custom controllers can create multiple benefits for the visiting experience. They bring a form of immersion and social engagement that cannot be found in traditional controllers. They also support the 'seriousness' in serious gaming. This is done by enabling the user to consider interactions before acting, which gives them time to learn. To ensure that people still enjoy the experience, the custom controller can increase engagement through social interaction and use an attractive and innovative appearance, where physical and sensory interactions can happen.

Appendix A: Interview notes 100%FAT

Design process:

1. *Receiving the idea:*
    a. *Client should put as much as possible on paper*
    b. *Where is it build: lighting, space, possibilities*
    c. *What does the installation need?*
        i. *boundary conditions (time, price, contract)*
        ii. *Client should put information down on paper*
    d. *Is co-creation possible? Take the client with you at every step*
    e. *Contract: After-care should be clear and who pays when something goes wrong*
2. *Brainstorming idea:*
    a. *Creative sessions with the whole team.*
    b. *Moodboard (good for the client!)*
    c. *Find available case studies in other fields like cinema*
    → find the creator for more information
    d. *Having an idea does not mean you have a project yet.*
3. *Design:*
    a. *Shape, software, hardware / electronics.*
    b. *Clients want visuals.*
    c. *Testing with prototypes if possible*
4. *Execution:*
    a. *Building: needs to be sturdy and software does not break (also not with updates)*
    b. *Testing:*
        i. *with team, client and if possible with real users.*
        ii. *Test first in the lab and then on location if possible.*
        iii. *Test the hardest concept first.*
    c. *User stories*
    d. *Make sure that it can be used for a longer period of time: turning off updates on the computer to ensure the software stays the same.*

Problems in the design process. Sometimes the design process is reversed:

- *Clients sometimes come with ready-made projects because it is a design studio*
    - *Plan is made and feasibility is studied to see if design is realistic*
    - *Most steps are skipped*
- *Clients sometimes want propositions with prices*
    - *Time is of the essence to give the proposition*
    - *Hobbyists are way cheaper competitors*
    - *Design is the first step to see different components with prices*
    - *Work backwards later to improve the design*

Miscellaneous:
Serious games are risky as they are hard to balance for everyone to use.
Information sticks more when you are actively participating.

Appendix B: Notes museum visit NEMO

4 floors with different themes. Each floor increases the target audience from small children to late teens and adolescents. This is because visiting can be tiring for younger children.

Lots of families with children were in the museum. Even though it was clearly targeted to children, the parents also interacted with the installations.

Learning through doing:
The installations have short descriptions and a lot of interaction. Descriptions are mostly pushed to the side though. They were being put on walls in corners or written on the floor. Not a lot of people seem to read.
Attractions had a lot of real-life elements like attractions with real water, sand or other physical objects. According to NEMO, the attractions that were most popular on the first floor were the Plasma ball and bubble ring installation. These attractions were visually interesting from a distance and had people interacting with it, in a physically interesting way.

Accessibility:
Some installations have stairs for children to access installations that are too high for them. People with disabilities cannot use these installations.

Examples of personally interesting installations (from a design standpoint):

- *Ghostly glass:*
  Interesting because of the use of science with technology in a unique way. Using a glass mirror to project an image on a glass plate. You can place your hand behind it to make the image float like a hologram on top of your hand. The effect is called Pepper's ghost.
- *Colour filter:*
  Filters coloured text going through each other using coloured transparent plastic plates. When looking through it, the text is revealed. Although it is not too visually stunning or popular. It is a more innovative way to display the information about why this effect works.
- *Water Power:*
  The water power exhibit exists out of two interesting parts. A big installation with real water to experiment with and an interactive projection mapped table. The table has the shape of a hilly landscape with basins. The users can place sandbags to block certain paths off or open drains to let the water go out. The technology using depth sensors is fun to play with, but sometimes a bit unclear.
- *The Machine (Ball factory):*
  Logistical processes factory with robot arms. Users assemble a product with a minigame that is displayed on screens. By throwing balls in the right hole the user sorts and

assembles the products on the factory floor. A fun way to teach about real applications without text.

Appendix C: Notes museum visit Corpus

2 parts: Guided tour through the human body & interactive part

***Tour**:*
Lots of visuals and other sensory stimuli. You are really inside the body
Physical environment with rich immersion. It feels like a maze, but you do not get lost. Excellent to present the human body.
The tour is mostly an audio guided video using a couple of physical environmental features

Features like a real tongue texture to walk on and being in a nose that is filled with artificial smell stands out and should be used more if possible. Pretty cool.
The museum is not interactive. The user could be involved more or incentivised to do more.
The pace is dictated by the length of the videos.

- *The good part is the amount of control from the museum. They can have a story that the user goes through.*
- *The bad part is that the user cannot dictate the pace to its own liking.*

Accessibility is a problem as anything bigger than a regular wheelchair without legs sticking out could not participate in the tour at all. The visit was done with a regular wheelchair though, so it worked out.

***Interactive part**:*
There are "blood veins" following where you should go. These have screens on them with information. There are 5 floors of interactive installations.

Positives

\+ *Interactions match specific themes*
\+ *Learning about not just the human body but about being healthy*
\+ *Visual and audible stimulation*
\+ *Text is written down in both Dutch and English*
\+ *Lots of technology*

Negative

- *Most installations have little 'unique' controls or sensory feedback. 90% screens with normal audio.*
- *Some screens are placed too high to access for disabled people.*
- *More than half of the digital installations are only in Dutch. Not inclusive but no problem if the target audience is mostly Dutch*
- *Some information can be questioned, e.g.: Everyone should drink milk! → Not true for everyone*

- *The only benches available are at a corner of the exhibit.*
  → *if in the middle the interaction between people could perhaps be better.*
- *Some games could be more adaptive to the difficulty level of the user.*

Dunea duin & water: one of the more unique installations because you can pump actual water. Feedback for the player could improve though, as it is unclear that at some point you should stop pumping and need to press buttons.

Voedsel groepen: Installation in the form of a cantina. Choose breakfast, lunch and dinner and you will get how healthy you are.

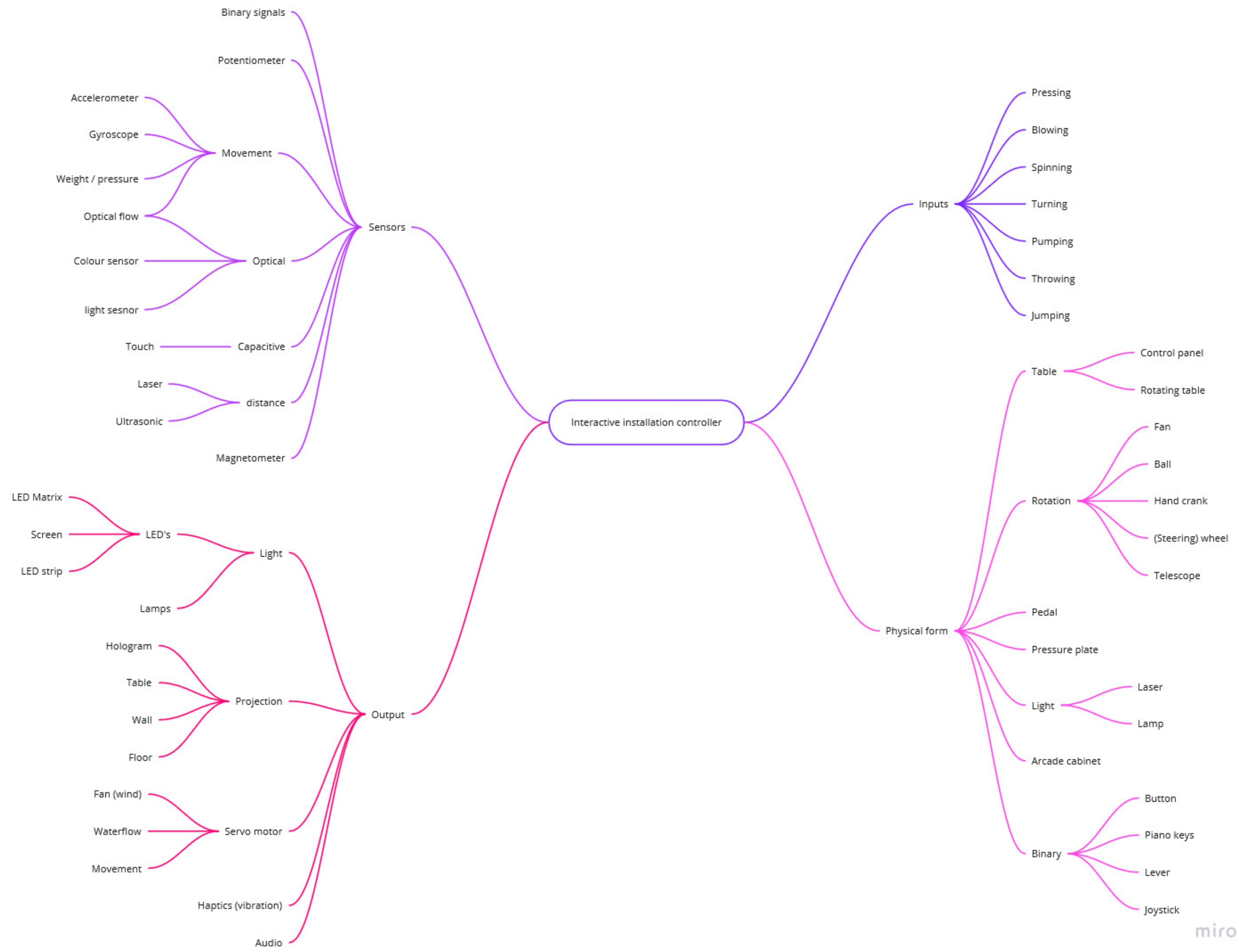
Appendix D: Literature matrix

Fitting answer per source for each subquestion	Learning from interactive museum installations about interaction design for public settings (Hornecker & Stifter, 2006)	Learning Visual Programming by Creating a Walkable Interactive Installation (Hadjakos et al., 2015)	Museum and Art Gallery Experience Space Characteristics: an Entertaining Show or a Contemplative Bathe? (McIntyre, 2009)	Human-Centered Artificial Intelligence for Designing Accessible Cultural Heritage (Pisoni et al., 2021)	Trajectories of Physical Engagement and Expression in a Co-Creative Museum Installation (Long et al., 2019)	Adviesrapport Cosmos Sterrenwacht (Hakvoort et al., 2020)	The art of Game Design (Schell, 2020)	Synthesis (conclusion per sub-question)
Howcan interactive installations help in the learning process?	Use short engagement, providing an early success experience and simple, small amounts of information, while increasing the complexity of information and/or activity with extended engagement. But besides being an entertaining experience, museums aim to educate the public. As indicated above, we regard prolonged (or repeated) interaction as positive, indicating that visitors find an exhibit engaging and interesting. Somewhat orthogonal to duration is intensity of engagement (someone can merely play around or be mentally engaged with content)	/	However, if the fundamental aim of a museum / gallery is to enhance learning, there could be a need to refocus on the later part of the process as described to obtain the correct mix: the arousing curiosity / questioning to promote Learning. This would perhaps move away from the dangers of the Attracting and Entertaining elements becoming too dominant or overbearing in the design of the museum or gallery experience. (p.165) The desired gallery experience was one of learning via the consideration of, immersion in and reflection upon the objects and environments presented as having artistic relevance. The experience was highly reflective and needed time and space to accomplish the individual's goals. (p. 159)	The model nicely illustrates that learning in cultural heritage settings are complex and influenced by various factors. Taking into account the personal and the socio-cultural context it becomes clear that not all visitors enter a museum or cultural heritage sites with the same amount of prior knowledge, cultural capital and resources, and also their attitudes, motivation and interest may differ. … Action, interaction, prolonged engagement and continued reflection on the content or the collection is important in facilitating learning and shaping positive outcomes. (p. 9)	both interaction designers and museum practitioners have recognized that physical interaction has the potential to make learning experiences more intuitive and engaging (p. 247) Challenge plays an important role in both learning and the creative process. The key is that the challenge has to be at a level that is just beyond the learner's skill level, but not so far that they get discouraged. (p. 255) there is a lack of empirical research assessing whether tangible interaction actually leads to learning gains and which design features best promote such gains. (p. 247) Creative Exploration: Participants who have "figured out" how to use the table want to go back and choose sounds and sound sequences that fit their creative goals. (p. 252)	Ten eerste moet er rekening gehouden worden met de complexiteit van de informatie, wat mogelijk is door gebruik te maken van levels, voorbeelden en hints. Het tweede aspect omvat de vormgeving en de wijze waarop de Informatie overgebracht wordt. Dit moet aansluiten op de leerstijlen en de belevingswereld van de doelgroep. Dit kan bereikt worden wanneer er ervaringen aan bod komen in de game via simulaties of video's. Een verhaallijn en/of triggers (vibraties, geluiden, kleuren, licht) zorgen er daarnaast voor dat de informatie spannend overgebracht wordt, waardoor de aandacht eenvoudiger erbij te houden is. Het derde en laatste aspect omvat de manier waarop men interacteert met de informatie. De game moet hiervoor zo ingericht zijn dat informatie zowel	We know that keeping the player in the flow channel is desirable. If play is too challenging, the player becomes frustrated. if the player succeeds too easily, they can become bored. this can be particularly difficult since players may have all different levels of skill.	2x Arousing curiosity / questioning 2x Take into account the personal and the socio-cultural context 2x prolonged engagement 2x reflection 2 x +, 1 x - (physical) interaction 4x Challenge level Stimulate senses Visual and auditory information instead of text Give time and space Creative expression

					designing to facilitate reflection and mental-model revision can encourage deeper engagement and creative expression. (p. 255)	visueel als auditief waar te nemen is. (p. 8)		
What is the ideal visit experience of an exhibit?	It's important to have provision of space and visibility of the exhibit as well as of the interaction going on, which allows for scaffolding, commenting and discussing Research has demonstrated that content that is visible for several people simultaneously can stimulate interaction between visitors Best ways to make an installation: Allow for productivity, creativity and/or communication Stations allowing 'real' interactivity and creation of personal content (not just reading a given hypertext) were more intensely used Use Installations with a physical setup that can host a small group Provides visibility Allow for handing over control or taking on different roles	Simple Impression: Users typically interact with an exhibit for the first time and only once. Therefore, the exhibit should be easy-to-use and that simplicity should also be conveyed visually. Cooperative experience: Exhibits are commonly visited by groups … Bystanders should be able to experience the exhibit passively, which also helps to attract new users. Easy Handover: There should be a simple way to hand over the control from one user to another and still provide a meaningful interaction. Immersive Display: By using large displays it is easier to immerse the user into the virtuality of the exhibit, which may help to provide an engaging experience. (p. 2) Attraction Space: By looking or sounding interesting, beautiful or innovative, an installation can grab the attention of visitors and motivate them to start	A physical building with objects inside, where things happened in relation to people and objects coming together in spaces, was the key encompassing focus of a museum's meaning for visitors in this study. The desired gallery experience was one of learning via the consideration of, immersion in and reflection upon the objects and environments presented as having artistic relevance. The experience was highly reflective and needed time and space to accomplish the individual's goals. (p. 159)	The project developers showcase the resulting design, the design method and approach to inclusive design they follow and the key dimensions of it, namely culture, age and disabilities on the human side, and time, cost and space on the technology side. (p. 8) We argue that the experience of a visitor is shaped by the following three interacting context factors: the personal, the physical and the social context. the personal context relates to the psychological make-up and state, the prior knowledge, attitudes, experiences, motivation and interests that visitors bring with them when they engage in cultural heritage related activities and that shape their experiences. The physical context refers to the building, the artifacts and the ambiance, all factors that influence the way visitors move through a museum and what catches their attention. The social cultural context is focusing more on the cultural background of the visitors and the	an "ideal" trajectory of physical engagement would involve participants moving sequentially through the three stages of engagement (initial engagement, exploratory engagement and expressive engagement), with a significant period of time spent at L3 towards the end of the interaction (p. 251) designing to facilitate reflection and mental-model revision can encourage deeper engagement and creative expression. (p. 255)	Een verhaallijn en/of triggers (vibraties, geluiden, kleuren, licht) zorgen er daarnaast voor dat de informatie spannend overgebracht wordt, waardoor de aandacht eenvoudiger erbij te houden is.	but we must always remember that we are not designing just game mechanics, but an entire experience. and aesthetic considerations are part of making any experience more enjoyable. Good artwork can do wondrous things for a game audio feedback is much more visceral than visual feedback and more easily simulates touch.	3x Stimulate senses 2x Easy-to-use 2x Own time and space to accomplish goals Easy Handover 2x Immersion Physical interaction 2x (self-)reflection 2x Catered to the user's background 3x Connected group experience Visibilityof everything 2x Attract user

		interacting with the exhibit. Overstimulation may be counterproductive.		type of interactions they engage in. (p. 9) These should be engaging but intuitive to use so that no staff attendance is needed.					
What benefits do custom controllers have compared to traditional ones?	visitors tend to focus on the kinds of media that they are familiar with instead of getting exposed to unfamiliar ones This shows that mixed media that combine haptic input devices with computational augmentation are effective in addressing diverse groups of visitors and arousing interest in unfamiliar topics. It's important to have provision of space and visibility of the exhibit as well as of the interaction going on, which allows for scaffolding, commenting and discussing Research has demonstrated that content that is visible for several people simultaneously can stimulate interaction between visitors Giving an performance by users is also a form of engagement to attract visitors	Innovative Appearance: Instead of using standard interaction setups (mouse, keyboard, computer screen), exhibits can use non-standard input and output devices to provide an innovative appearance. Easy Handover: There should be a simple way to hand over the control from one user to another and still provide a meaningful interaction. Exhibits are commonly visited by groups, at least two persons should be able to use an interactive exhibit at the same time. Bystanders should be able to experience the exhibit passively, which also helps to attract new users.	The idea that virtual interaction with objects at a distance would be equally meaningful was not supported by any of the respondents. (p. 159) Interaction with displays meant the ability to appreciate them in an intra-personal way by heightening both the visual and other sensual nature of a visit and stimulating the use of the imagination. (p. 160)	The novelty and usability from interacting with a technology whose interaction is like "any physical book" provided a positive effect. The interactive ones aroused user interest in contents. (p. 6) they often come with a group, Designed technologies should be able to deal with a constant stream of visitors at peak times.	/	Wanneer er fysieke attributen of knoppen zijn die men moet gebruiken om het spel te kunnen spelen, ontstaat er meer fysieke interactie met de expositie. Deze interactie kan dan weer een positieve invloed hebben op hoe goed men zich kan focussen op het spel, omdat ze echt bewust bezig moeten zijn met de knoppen / attributen (p. 65)	Clearly, playing with other people is natural and, in fact, the preferred way for us to play games. but why? for pleasure, for challenge, for judgment, for rewards, for flow, for transcendence, and many more. When touch games first appeared, many gamers complained loudly. a touchable screen was a poor substitute for a gamepad—that is, when it tried to mimic a gamepad. Soon, games started to appear that wouldn't have been possible without touch, and people felt very differently. novelty in games is very important—but giving the right amount of familiarity, especially in your immediate surroundings, can give a feeling of presence that is surprisingly strong.	2x Innovative Appearance Haptic feedback 3x Familiar physical objects 2x Physical over virtual 3x Group interaction 2x Performance space Stimulate senses Sturdy Easy handover

Appendix E: [Mind map]



Appendix F: Morphological design chart

Installation 1: Solar system						
Nr	Subfunction	Solution 1: Mobile phone	Solution 2: Xbox (adaptive) controller	Solution 3: Arcade setup	Solution 4: Spaceship	Solution 5: Mouse Ball
1	Visuals	Projection + controller on phone	Projector + sun ball form	Computer screens (2 or 4)	Projector	Projector
2	Audio	Speakers	Headphones	Speakers	Build-in speakers	Build-in speakers
3	Spaceship steering	Screen Joystick	Xbox joystick	Joystick	Steering wheel	Custom Mouse ball
4	Spaceship speed	Screen Joystick	Xbox joystick	(boost) button	Thrust Lever	Rotation speed ball
5	UI interaction	Physical buttons	Xbox joystick + buttons; Player 1	Joystick + button	Button	
6	Planet discovered info	Phone screen + Projector	Small 1 person LED-screen	Digital	Seperate mini screen	Light up info board
7	Fuel meter	Phone screen	Digital	Row of LED's	Fuel gauge	Water cylinder

Installation 2: Sun processes								
Nr	Subfunction	Solution 1: control panel	Solution 2: Playbox	Solution 3: Projector table	Solution 4: sun lamp	Solution 5: Pinball	Solution 6: Ball games	Solution 7: Touchscreen
1	Visuals	Projector	Projector / Computer screen	Projection on table + sun ball form	Touch screen	Projection	Projection	Screen
2	Audio	Build-in Speakers	Mini speaker for individual comp.	Build-in speakers	Speaker	Speaker	Speakers	Speakers
3	Moving atoms	Two joystick	Tilting box filled with balls	Azure Kinect	Touch screen	Pinball gates	Big trackball (Mouse)	Dragging
4	Sun meter visual	Row of LED's	Thermometer	Digital UI	Analog gauge	Row of LED's	Tiny screen	Digital
5	Regulate sun meter up	Slider / dial that slides back down	blacksmith blower / pump	Hand crank	Hand crank for lamp	Button mash	Throw red ball at sensor	Button
6	Regulate sun meter down	Reverse slider	steam train flute / dynamite press	Emergency button	Cover sun lamp / wind?	Lose the pinball	Throw blue ball at sensor	Button

Installation 3: Sun lifecycle and the earth							
Nr	Subfunction	Solution 1: Time machine	Solution 2: projection room	Solution 3: Globe controller	Solution 4: Telescope	Solution 5: Kinect	Solution 6: IR tracking
1	Visuals	Space ship with projection screen	2 Projectors (curved wall?)	Globe projection	Small Screen	Projection	Projection
2	Audio	Space headset (headphones)	Speakers	Speakers	Radio speaker	Speakers	Speakers
3	Turn camera	Wheel	Automatic / not needed	Turn globe	Rotate telescope (gyroscope)	Moving left / right	Move controller remote
4	Move timeline	slider with handle	Bike / hourglass ?	Move disk	Lever	Buttons	wheel (of fortune)
5	Click on points of interest	Button	Kinect	Button	Hold still or button	Hold hand	Button on remote
							https://www.pcgamer.com/how-to-build-your-own-ir-head-tracker/

Appendix G: Question setup

Section 1			
Nr	Question	Dimension	Source
1	I could easily see everything the other person was doing with the installation	Social engagement	Self-made
2	I enjoyed watching others play with the installation	Performance (Social eng.)	Self-made
3	Watching someone play with the installation made me want to play it too	Performance (Social eng.)	Self-made
4	I could interact together with others while playing with the installation	Social engagement	Self-made
5	I had the feeling we were playing the game together on the installation	Social engagement	Self-made
6	I could easily see everything the other person was doing with the Xbox controller	Social engagement	Self-made
7	I enjoyed watching others play with the Xbox controller	Performance (Social eng.)	Self-made
8	Watching someone play with the Xbox controller made me want to play it too	Performance (Social eng.)	Self-made
9	I could interact together with others while playing with the Xbox controller	Social engagement	Self-made
10	I had the feeling we were playing the game together with the Xbox controllers	Social engagement	Self-made
11	The height of the installation was appropriate	Accessibility	Self-made
12	I reached all the physical components comfortably	Accessibility	Self-made
13	The look of the controller fits with the game	Thematic look (precondition immersion)	Self-made
14	I felt like I was active while playing	Performance (Social eng.)	Self-made

15	I could recognise what physical components of the installation would do	Familiar object (precondition usability)	Self-made
Section 2			
Nr	Question	Dimension	Source
1	I felt I lost track of time when playing with the installation	Immersion	Moreno et al. (2016)
2	I felt I was inside the game while playing with the installation	Immersion	Moreno et al. (2016)
3	I liked playing with the installation	Immersion	Moreno et al. (2016)
4	I was aware of events occurring in the real world around me using the installation	Immersion (*Reversed question)	Norman (2010)
5	The installation distracted me from playing the game	Immersion	Norman (2010)
6	I felt I lost track of time when playing with the Xbox controller	Immersion	Moreno et al. (2016)
7	I felt I was inside the game while playing with the Xbox controller	Immersion	Moreno et al. (2016)
8	I liked playing with the Xbox controller	Immersion	Moreno et al. (2016)
9	I was aware of events occurring in the real world around me using the Xbox controller	Immersion (*Reversed question)	Norman (2010)
10	The controller distracted me from playing the game	Immersion	Norman (2010)
11	I was able to clearly identify what game pieces/objects/models represented	Usability	Moreno et al. (2016)

12	I was able to anticipate what would happen next in response to the actions I initiated	Usability	Moreno et al. (2016)
13	I adjusted quickly to the game	Usability	Norman (2010)
14	The controls for the game were appropriate	Usability	Moreno et al. (2016)
15	The controls for the game felt natural	Usability	Moreno et al. (2016)
16	The controller interfered with playing the game	Usability	Norman (2010)
17	The game was responsive to actions that I initiated (or performed)	Usability	Norman (2010)

Appendix H: Questionnaire

These questions will ask you about the differences between playing with the custom controllers vs. regular controllers. Please indicate where your opinion lies on the scale from strongly disagree to strongly agree.

Section 1

Nr	Question	Strongly disagree	Slightly disagree	Neutral	Slightly agree	Strongly agree
1	I could easily see everything the other person was doing with the installation	☐	☐	☐	☐	☐
2	I enjoyed watching others play with the installation	☐	☐	☐	☐	☐
3	Watching someone play with the installation made me want to play it too	☐	☐	☐	☐	☐
4	I could interact together with others while playing with the installation	☐	☐	☐	☐	☐
5	I had the feeling we were playing the game together on the installation	☐	☐	☐	☐	☐
6	I could easily see everything the other person was doing with the Xbox controller	☐	☐	☐	☐	☐
7	I enjoyed watching others play with the Xbox controller	☐	☐	☐	☐	☐
8	Watching someone play with the Xbox controller made me want to play it too	☐	☐	☐	☐	☐
9	I could interact together with others while playing with the Xbox controller	☐	☐	☐	☐	☐
10	I had the feeling we were playing the game together with the Xbox controllers	☐	☐	☐	☐	☐
11	The height of the installation was appropriate	☐	☐	☐	☐	☐
12	I reached all the physical components comfortably	☐	☐	☐	☐	☐
13	The look of the controller fits with the game	☐	☐	☐	☐	☐

14	I felt like I was active while playing	☐	☐	☐	☐	☐
15	I could recognise what physical components of the installation would do	☐	☐	☐	☐	☐

Section 2

Nr	Question	Strongly disagree	Slightly disagree	Neutral	Slightly agree	Strongly agree
1	I felt I lost track of time when playing with the installation	☐	☐	☐	☐	☐
2	I felt I was inside the game while playing with the installation	☐	☐	☐	☐	☐
3	I liked playing with the installation	☐	☐	☐	☐	☐
4	I was aware of events occurring in the real world around me using the installation	☐	☐	☐	☐	☐
5	The installation distracted me from playing the game	☐	☐	☐	☐	☐
6	I felt I lost track of time when playing with the Xbox controller	☐	☐	☐	☐	☐
7	I felt I was inside the game while playing with the Xbox controller	☐	☐	☐	☐	☐
8	I liked playing with the Xbox controller	☐	☐	☐	☐	☐
9	I was aware of events occurring in the real world around me using the Xbox controller	☐	☐	☐	☐	☐
10	The controller distracted me from playing the game	☐	☐	☐	☐	☐
11	I was able to clearly identify what game pieces/objects/models represented	☐	☐	☐	☐	☐
12	I was able to anticipate what would happen next in response to the actions I initiated	☐	☐	☐	☐	☐
13	I adjusted quickly to the game	☐	☐	☐	☐	☐

14	The controls for the game were appropriate	☐	☐	☐	☐	☐
15	The controls for the game felt natural	☐	☐	☐	☐	☐
16	The controller interfered with playing the game	☐	☐	☐	☐	☐
17	The game was responsive to actions that I initiated (or performed)	☐	☐	☐	☐	☐

Any remarks?

____

____

____

____

____

____

References

Akpan, I., Marshall, P., Bird, J. & Harrison, D. (2013). Exploring the effects of space and place on engagement with an interactive installation. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '13). Association for Computing Machinery, New York, NY, USA, 2213–2222. https://doi.org/10.1145/2470654.2481306

Ali, S., Bedwell, B., & Koleva, B. (2018). Exploring relationships between museum artefacts through spatial interaction. Proceedings of the 10th Nordic Conference on Human-Computer Interaction - NordiCHI '18. https://doi.org/10.1145/3240167.3240217

Back, M., Gold, R., Balsamo, A., Chow, M., Gorbet, M., Harrison, S., MacDonald, D., & Minnerman, S. (2001). Designing innovative reading experiences for a museum exhibition. *Computer*, *34*(1). https://doi.org/10.1109/2.895121

Bowman, D. A., & McMahan, R. P. (2007). Virtual reality: how much immersion is enough? *Computer*, *40*(7). https://doi.org/10.1109/MC.2007.257

Burdea, G., Kim, N., Polistico, K., Kadaru, A., Grampurohit, N., Roll, D., & Damiani, F. (2021). Assistive game controller for artificial intelligence-enhanced telerehabilitation post-stroke. *Assistive Technology: The Official Journal of Resna*, *33*(3), 117–128. https://doi.org/10.1080/10400435.2019.1593260

Companje, R., van Dijk, N., Hogenbirk, H., & Mast, D. (2006). Globe4D: time-traveling with an interactive four-dimensional globe. In Proceedings of the 14th ACM international conference on Multimedia (MM '06). Association for Computing Machinery, New York, NY, USA, 959–960. https://doi.org/10.1145/1180639.1180850

de Greeff, J. W., Bosker, R. J., Oosterlaan, J., Visscher, C., & Hartman, E. (2018). Effects of physical activity on executive functions, attention and academic performance in preadolescent children: a meta-analysis. *Journal of science and medicine in sport*, *21*(5), 501–507. https://doi.org/10.1016/j.jsams.2017.09.595

Geller, T. (2006). Interactive tabletop exhibits in museums and galleries. *Ieee Computer Graphics and Applications*, *26*(5). https://doi.org/10.1109/MCG.2006.111

Hadjakos, A., Schulze, H., Düchting, A., Metzger, C., Ottensmann, M., Riechmann, F., Schneider, A., & Trappmann, M. (2015). Learning Visual Programming by Creating a Walkable Interactive Installation. In Proceedings of the Audio Mostly 2015 on Interaction With Sound

(AM '15). Association for Computing Machinery, New York, NY, USA, Article 19, 1–8. https://doi.org/10.1145/2814895.2814914

Hakvoort, R., Hamstra, K., & Ross, J., (2020). Adviesrapport Cosmos Sterrenwacht. (No URL available)

Hornecker, E., & Stifter, M. (2006). Learning from interactive museum installations about interaction design for public settings. 135-142. https://doi.org/10.1145/1228175.1228201.

Long, D., McKlin, T., Weisling, A., Martin, W., Guthrie, H., & Magerko, B. (2019). Trajectories of Physical Engagement and Expression in a Co-Creative Museum Installation. In *Proceedings of the 2019 on Creativity and Cognition* (*C&C '19*). Association for Computing Machinery, New York, NY, USA, 246–257. https://doi.org/10.1145/3325480.3325505

Mader, A. H., & Eggink, W. (2014). A Design Process for Creative Technology. In E. Bohemia, A. Eger, W. Eggink, A. Kovacevic, B. Parkinson, & W. Wits (Eds.), *Proceedings of the 16th International conference on Engineering and Product Design, E&PDE 2014* (pp. 568-573). (E&PDE). The Design Society. https://www.designsociety.org/publication/35942/a_design_process_for_creative_technology

Markopoulos, P., Read, J. C., MacFarlane, S., & Hoysniemi, J. (2008). *Evaluating Children's Interactive Products: Principles and Practices for Interaction Designers (Interactive Technologies)* (1st ed.) [E-book]. Morgan Kaufmann.

Martin, M., Shen, Y. (2011) Defining and Leveraging Game Qualities for Serious Games. Selected Papers and Presentations Presented at MODSIM World 2010 Conference Expo. 7(4):944-951. https://ntrs.nasa.gov/citations/20110012059

McIntyre, C. (2009). Museum and art gallery experience space characteristics: an entertaining show or a contemplative bathe? *International Journal of Tourism Research*, *11*(2), 155–170. https://doi.org/10.1002/jtr.717

Molenbroek, J. F. M., & Jürgens, H. (1997). *DINED dutch growth diagrams*. DINED Anthropometric Database TUDelft. Retrieved March 30, 2022, from https://dined.io.tudelft.nl/en/database/tool

Moreno, A., van Delden, R., Poppe, R., Reidsma, R., Heylen, D. (2016)
Augmenting playspaces to enhance the game experience: A tag game case study, Entertainment Computing, 16(2016), 67-79. https://doi.org/10.1016/j.entcom.2016.03.001.

Müller, J., Alt, F., Michelis, D., & Schmidt, A. (2010). Requirements and design space for interactive public displays. MM'10 - Proceedings of the ACM Multimedia 2010 International Conference. 1285-1294. https://doi.org/10.1145/1873951.1874203.

Nielsen, J. (2012). *Thinking aloud: The #1 usability tool.* Nielsen Norman Group. Retrieved April 19, 2022, from https://www.nngroup.com/articles/thinking-aloud-the-1-usability-tool/

Norman, K.L. (2010). *Development of Instruments to Measure Immerseability of Individuals and Immersiveness of Video Games.* Technical Report LAPDP-2010-03, HCIL Technical Report 12-5-10, University of Maryland, College Park, MD 20742. https://doi.org/10.1.1.228.56

Oinas-Kukkonen, H., & Harjumaa, M. (2009). Persuasive Systems Design: Key Issues, Process Model, and System Features. Communications of the Association for Information Systems. 24. https://doi.org/10.17705/1CAIS.02428

Pisoni, G., Díaz-Rodríguez, N., Gijlers, H., & Tonolli, L. (2021). Human-Centered Artificial Intelligence for Designing Accessible Cultural Heritage. *Applied Sciences*. 11(2):870. https://doi.org/10.3390/app11020870

Schell, J. (2020). The art of game design: a book of lenses (3rd ed.). CRC Press LLC. https://doi.org/10.1201/b22101

Segale, H. (2016). Children play with UC Davis' Augmented Reality Sandbox at the 2016 USA Science and Engineering Festival. Retrieved November 11, 2021, from https://www.ucdavis.com/news/school-sandbox-no-other

Steenbekkers, L. P. A., Molenbroek, J. F. M., & Dirken, J. M. (1993). *Kima1993*. DINED Anthropometric Database TUDelft. Retrieved March 30, 2022, from https://dined.io.tudelft.nl/en/database/tool

Sutherland, J., & Schwaber, K. (2020). *The Scrum Guide* (Revised ed.). Retrieved February 10, 2022 from https://scrumguides.org/scrum-guide.html

Tullis, T., & Albert, B. (2013). *Measuring the user experience : collecting, analyzing, and presenting usability metrics*. Elsevier. Retrieved February 6, 2022, from https://doi.org/10.1016/B978-0-12-415781-1.00004-2

van Aalst, I., & Boogaarts, I. (2002). From Museum to Mass Entertainment: The Evolution of the Role of Museums in Cities. *European Urban and Regional Studies*. 9(3):195-209. https://doi.org/10.1177/096977640200900301

Varvasovszky, Z., & Brugha, R. (2000). A stakeholder analysis. *Health Policy and Planning*, *15*(3), 338–45. https://doi.org/10.1093/heapol/15.3.338

Zeiler, W., Savanovic, P., & Quanjel, E. (2009) Morphology: A Tool for Design and Analysis of Design. *DS 58-5: Proceedings of ICED 09, the 17th International Conference on Engineering Design, Vol. 5, Design Methods and Tools*, Palo Alto, CA, USA. Retrieved from https://www.designsociety.org/publication/28701/Morphology%3A+A+Tool+for+Design+and+Analysis+of+Design

Footnotes

[1]The HTC Vive is a commercial virtual reality headset. More information can be found on the website (https://www.vive.com/)

[2]The Oculus Rift is a commercial virtual reality headset. More information can be found on the website (https://www.oculus.com/rift/)

[3]The Microsoft Hololens is a pair of state-of-the-art AR glasses. More information can be found on the website (https://www.microsoft.com/en-us/hololens)

[4]The Magic Leap One is a wearable AR computer for enterprise productivity. More information can be found on the website (https://www.magicleap.com/magic-leap-1)

[5]Lü is a projection system made for making an educational environment where kids are engaged physically, intellectually and socially-emotionally. More information can be found on the website (https://play-lu.com/)

[6]The LUMOplay is a platform making any display interactive. It includes a hardware kit with sensors and software. More information can be found on the website (https://www.lumoplay.com/)

[7]Springlab is a floor projection system. It enables physically active learning for children. More information can be found on the website (https://www.springlab.nl/)

[8]The Azure Kinect is a soft- and hardware kit to process object positioning and movement in an open space. More information can be found on the website (https://www.microsoft.com/en-us/d/azure-kinect-dk/8pp5vxmd9nhq)

[9]The Tovertafel projects interactive images onto flat surfaces that promote meaningful play for people with cognitive challenges. More information can be found on the website (https://www.tover.care/us/tovertafel/)

[10]The Euclideon Holotable is a holographic technology system for showing fully interactive large-scale architectural designs. More information can be found on the website (https://axiomholographics.com/)

[11]UC Davis Open-Source Sandbox is a project by multiple research centres. They make 3D visualisation applications using the Microsoft Kinect, projecting on sandbox tables. More information can be found on the website (https://web.cs.ucdavis.edu/~okreylos/ResDev/SARndbox/)

[12]100%FAT is a creative agency and producer of customised interactive installations based in Enschede. More information can be found on the website (https://www.100fat.nl/)

[13]AcE Craft is a Creative Engineering company specialising in 3D printing. More information can be found on the website (https://www.acecraft.eu/)

[14]Expeditie NEXT is a national science fair in the Netherlands consisting of universities, colleges, and museums. More information can be found on the website (https://expeditienext.nl/)