

# LEGO ALMA: Adapting an installation for accessibility and engagement

Master's thesis in Computer science and engineering

Tarek Alfutih, Adam Wikström



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UNIVERSITY OF  
GOTHENBURG

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Gothenburg, Sweden 2026

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## Abstract

A large number of installations in visitor centers and museums struggle with providing engaging and accessible experiences for younger audiences, especially when they utilize tangible interfaces. Thus, this project was started with the aim of clearly defining key factors that help improve accessibility and user engagement. To identify these factors the already existing LEGO ALMA installation at Onsala space observatory's visitor center was used as a testbed for prototype evaluation. The aim was to evaluate how different aspects of a tangible interface impact accessibility and user engagement. The prototypes tested during the project were developed using an iterative user-centered design process to reflect a real world development scenario. The results from testing the low, mid, and high fidelity prototypes identified four key factors for improving already existing installations. They should aim to reduce or prevent information overload, combine animation with text in instructions, use audio to draw the users' attention to specific areas, and limit the users' available resources to promote experimentation.

Keywords: accessibility, engagement, interaction design, tangible interaction, science communication, education, LEGO ALMA, thesis.



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# Contents

<b>List of Figures</b>	<b>xi</b>
<b>1 Introduction</b>	<b>1</b>
1.1 Research Question . . . . .	2
1.2 Design challenge . . . . .	2
<b>2 Theory</b>	<b>5</b>
2.1 Related work . . . . .	5
2.2 Ethical and Social considerations . . . . .	9
<b>3 Methods</b>	<b>11</b>
3.1 Research through design . . . . .	11
3.2 Rapid and Iterative prototyping . . . . .	11
3.3 Wizard of Oz . . . . .	12
3.4 Triple Diamond . . . . .	13
<b>4 Design Process</b>	<b>15</b>
4.1 Initial observations . . . . .	15
4.1.1 Installation design . . . . .	15
4.1.2 User observations . . . . .	16
4.2 General plan . . . . .	16
4.3 Stakeholder interviews . . . . .	17
4.4 Field study . . . . .	18
4.5 Ideation . . . . .	21
4.6 Testing Procedures . . . . .	23
4.6.1 Low fidelity prototype testing . . . . .	23
4.6.2 Mid fidelity prototype testing . . . . .	23
4.6.3 High fidelity prototype testing . . . . .	24
4.7 Low fidelity prototyping . . . . .	24
4.8 Mid fidelity prototyping . . . . .	27
4.8.1 Prototype 1 . . . . .	28
4.8.2 Prototype 2 . . . . .	29
4.8.3 Prototype 3 . . . . .	31
4.8.4 Prototype 4 . . . . .	33
4.9 High fidelity prototype . . . . .	34
4.9.1 Testing . . . . .	35

<b>5</b>	<b>Results</b>	<b>37</b>
<b>6</b>	<b>Discussion and Conclusion</b>	<b>41</b>
6.1	Discussion . . . . .	41
6.1.1	Key factor 1: Reduce or prevent information overload . . . . .	41
6.1.2	Key factor 2: Balancing of resources . . . . .	42
6.1.3	Key factor 3: Input and output positioning . . . . .	44
6.1.4	Key factor 4: Appropriate audio implementation . . . . .	44
6.1.5	Key factor 5: Combining animation and text . . . . .	45
6.1.6	Key factor 6: Coherency between the physical and digital . . . . .	46
6.2	Future Work . . . . .	46
6.3	Conclusion . . . . .	47
	<b>Bibliography</b>	<b>49</b>
<b>A</b>	<b>LEGO ALMA Instructions</b>	<b>I</b>
<b>B</b>	<b>Initial Timeline</b>	<b>III</b>
<b>C</b>	<b>Questions asked during the stakeholder interviews</b>	<b>V</b>
<b>D</b>	<b>Ideation</b>	<b>IX</b>
<b>E</b>	<b>Low fidelity prototype testing</b>	<b>XVII</b>
<b>F</b>	<b>Mid fidelity prototype</b>	<b>XIX</b>

# List of Figures

3.1	Image of the triple diamond design process . . . . .	14
4.1	Image depicting the LEGO ALMA installation at Onsala space observatory. . . . .	16
4.2	Image showing the installation showcasing the human skeleton. . . . .	19
4.3	Images of notable installations in the human body section of Universeum . . . . .	20
4.4	Image showing one of many quiz-screens placed around the body section of Universeum . . . . .	20
4.5	Photograph depicting one half of the installation showcasing the endocrine system at Universeum. . . . .	21
4.6	Images depicting two different installations in the mathematics section at Universeum. . . . .	21
4.7	An illustration developed to present our initial idea for the installation. . . . .	22
4.8	Image of the low-fidelity prototype . . . . .	25
4.9	Selection view of the low-fidelity prototype . . . . .	25
4.10	Request to place an antenna on any white sensor . . . . .	26
4.11	Image of the observation view for the low fidelity prototype . . . . .	26
4.12	Image of the first mid fidelity prototype's observation view. . . . .	28
4.13	Photos from the LEGO ALMA installation interface in mid fidelity prototype 2. . . . .	30
4.14	Image of the screen for the antennas view in the second mid fidelity prototype . . . . .	30
4.15	Image of the video screen for the third mid fidelity prototype . . . . .	31
4.16	The observation view for LEGO ALMA in the third mid fidelity prototype. . . . .	32
4.17	The observation view for LEGO ALMA when users place only one antenna on white sensors. . . . .	33
4.18	The observation view for LEGO ALMA in the fourth mid fidelity prototype. . . . .	34
4.19	Images showing the difference between the original and altered versions of the high fidelity prototype's observation view. . . . .	36
5.1	High fidelity prototype's guide and reset views . . . . .	38
5.2	High fidelity prototype's observation view . . . . .	38
5.3	High fidelity prototype's video and selection views . . . . .	39

A.1	Instruction sheet for the LEGO ALMA installation that was placed beside the screen to guide users step by step. . . . .	I
C.1	First page of the questions asked to the stakeholders during the stakeholder interviews. . . . .	VI
C.2	Second page of the questions asked to the stakeholders during the stakeholder interviews. . . . .	VII
C.3	Third page of the questions asked to the stakeholders during the stakeholder interviews. . . . .	VIII
D.1	Image of sketch 1. . . . .	IX
D.2	Image of sketch 2. . . . .	X
D.3	Image of sketch 3. . . . .	X
D.4	Image of sketch 4. . . . .	XI
D.5	Image of sketch 5. . . . .	XI
D.6	Image of sketch 6. . . . .	XII
D.7	Image of sketch 7. . . . .	XII
D.8	Image of sketch 8. . . . .	XIII
D.9	Image of sketch 9. . . . .	XIII
D.10	Image of sketch 10. . . . .	XIV
D.11	Image of sketch 11. . . . .	XIV
D.12	Image of sketch 12. . . . .	XV
D.13	Image of sketch 13. . . . .	XV
D.14	Image of sketch 14. . . . .	XVI
E.1	Consent form provided to participants testing the low fidelity prototype.	XVII
E.2	Set of questions for testing low fidelity prototype. . . . .	XVIII
F.1	Screenshot of the mid fidelity prototype’s video view. . . . .	XIX
F.2	Screenshot of the mid fidelity prototype’s selection view. . . . .	XX
F.3	Screenshot of the mid fidelity prototype’s guide view. . . . .	XX
F.4	Screenshot of the mid fidelity prototype’s observation view. . . . .	XXI
F.5	Screenshot of the mid fidelity prototype’s reset view. . . . .	XXI

# 1

## Introduction

In the world of museums and science centers today, there is an increasing need to improve science communication and present information in ways that are understandable and accessible to people of different ages and backgrounds, (Shi, 2025). Scientific knowledge is increasingly communicated through both digital and physical experiences, making the design of these experiences more important than ever before, Shaer et al. (2009). Many science installations aim to spark curiosity and encourage visitors to explore and learn. However, their interfaces often make things more difficult than they need to be. In some cases, installations contain unintuitive or overly complex interfaces, which can make it difficult to communicate scientific knowledge and create engaging experiences in the way that was originally intended.

According to Sutcliffe (2016), when visitors receive a poor first impression of an installation due to being unable to understand the content or because the experience feels unintuitive, it may lead to feelings of frustration, anxiety, and even anger. As mentioned by Wang (2022), emotional and interactive elements can help users better understand complex information and create more meaningful experiences. However, when these emotions become negative, they may instead reduce engagement and have the opposite effect.

Additionally, communicating scientific concepts in museums and science centers is often challenging due to the complexity and amount of information being presented. Designing installations that are both educational and engaging therefore becomes a significant challenge for designers and stakeholders.

At the Onsala Space Observatory (OSO), located just south of Gothenburg, Sweden, there is a LEGO model of the ALMA telescope in Chile, appropriately called LEGO ALMA (“LEGO ALMA”, 2024). This installation was built to demonstrate radio interferometry for a wide audience. However, the original design relies on the presence of a guide or expert, which results in it not being particularly accessible to visitors wanting to use it on their own. Something which is only further exacerbated due to the way the information is presented and the complex nature of the subject itself. Thus, to improve accessibility and allow the installation to reach a broader audience, the installation needs to be redesigned.

The graphs currently displayed on the installations screen are unintuitive, making it difficult for visitors to understand what the installation is trying to teach. Additionally, the complex nature of the information also makes it so non-expert users

often require guidance to understand the installation. This creates frustration and reduces engagement with the experience. Because of these challenges, interaction design becomes important in improving visitors experiences and interactions with scientific installations. This is because the main goal of interaction design is to make systems intuitive and help users achieve their goals as effectively as possible (J. Li & Zhang, 2025). Furthermore, according to Wang (2022), interaction design has increasingly shifted from presenting information passively, toward creating more interactive and engaging experiences. This aligns with the needs of modern museums and science centers that want to inspire curiosity in visitors.

LEGO ALMA combines physical elements with digital interfaces, making it an example of tangible interaction. According to Shaer et al. (2009), tangible interaction combines physical and digital interaction by embedding computation into physical objects and environments. This allows users to interact with digital systems through hands-on engagement and physical movement, which can enhance learning. Because of this, creating a clear connection between the physical interaction and the digital feedback becomes essential in making the installation intuitive and educational.

Additionally, according to Falk and Dierking (2018, p. 7), learning in museums is influenced by three overlapping contexts: the personal context, the sociocultural context, and the physical context. This is particularly relevant for LEGO ALMA, where visitors interact together in a shared physical environment while exploring scientific concepts through tangible interaction.

### 1.1 Research Question

Based on these initial identified problems the following research question has been defined: *What are key factors to consider when improving accessibility and engagement in a tangible user interface aimed at science communication?*

### 1.2 Design challenge

The aim with this project is to develop a new and more inclusive design for the LEGO ALMA installation that caters to unsupervised exploration by a broader audience, not only astronomers. The installation's GUI is currently showing several graphs but they are not conducive for an understanding of the installation or its purpose. This means that the visuals on the screen needs to be changed into something that is clear and intuitive. Additionally, many users get confused about what they are supposed to do with the installation when they first approach. Because of this some sort of non-intrusive and clear instructions needs to be provided to the user to nudge them in the right direction.

The new prototype should help the user gain a new level of understanding about radio telescopes and interferometry. This is a complex data space which requires clear and visually rich interfaces to successfully transfer knowledge about something complex to a user that might not have any previous knowledge about the subject

(Lin et al., 2017). This is further supported by a previous study by Q. Li et al. (2024) which showed that good visual design increases visitor engagement in museums.

The main target audience for this project is children aged 12 to 18, which means that the feedback from the installation needs to be clear and easy to understand. Something it currently is not. In this age-range, they have a generally easier time learning new things. This creates an opportunity to design a new interface to spark their interest, and potentially even inspire a future passion for astronomy and space that they might not otherwise develop.



# 2

## Theory

### 2.1 Related work

Interaction design is not just limited to screens, pressing buttons, or moving a mouse, but also concerns how people interact with and understand information through their surrounding environment and interacting with different elements. According to Pike et al. (2009), interaction does not only occur inside the computer, but also through bodily movement, the surrounding environment, and the social context. When users interact with objects using their hands and learn through movement and exploration, the interaction becomes more powerful and meaningful. The researchers also argue that users are usually not interested in the tool itself, but rather in the problem or concept they are trying to understand.

Therefore, interaction should not only be seen as the use of an interface, but also as part of the process of thinking and learning itself. Interactive systems should allow users to experiment, explore, and manipulate things by themselves instead of only following predefined instructions. Additionally, combining physical and digital interaction can make learning feel more natural and understandable, especially in educational environments and science centers. As such, successful interactive systems should not only present information, but also support exploration, engagement, bodily interaction, and collaboration between users, which can help increase understanding and learning. This is directly relevant to LEGO ALMA, where visitors learn the scientific concept of interferometry through physical interaction with the installation by moving antennas instead of passively observing ready-made information.

Furthermore, for a successful interactive system, it is important to consider its accessibility. Accessibility is a key part of building inclusive communities where every user, regardless of ability, has equal access to information, services, and spaces (Iwarsson & Ståhl, 2003). Because of this, accessibility in this work focuses on how easy it is to use a system for individuals with no prior experience using it. A more accessible system means that it is intuitive, users quickly understand how they should interact with it, and any information given should be easily understandable.

Another important factor to consider for successful interactive systems is engagement. Engagement is a quality of the user experience, characterized by factors such as challenge, feedback, interactivity, perceived control, motivation, interest, and af-

fect Doherty and Doherty (2018). As such, for the purposes of this work, engagement refers to how engaged users are with a system. Examples of this is if they want to keep using the system after already using it for some time, or if they find the system fun to use in some way.

Designing installations in museums to promote learning and curiosity is something that has been done for many years. However, in a lot of cases this is done alongside a museum educator to aid those lacking the required prerequisite knowledge as mentioned by Tran (2007). This addition of an educator was further analyzed and led to the conclusion that quick lessons alongside the installations in a museum has beneficial effects on what students remembers from the visit. Therefore it is reasonable to say that utilizing educators to further the visitors' understanding is a good starting point for any exhibition.

Although many exhibitions provide interactive guides to help visitors understand installations better, the results are not as positive as one may expect (Axell & Hansson, 2023). The guide makes visitors read, follow instructions, and receive ready-made information instead of trying, discovering, thinking, and asking questions. In these cases, visitors become passive consumers of information rather than active and engaged participants in the experience. Visitors need entertainment, opportunities for thinking, and active participation, in addition to a sense of achievement. Although the interactive guide increases the time spent in the exhibition, it does not fulfill the other aspects necessary for the experience to be positive.

However, in the case of LEGO ALMA, the goal is for the user to be able to reach a state of understanding purely from the installation itself. This means that the installation needs to be designed to be as intuitive as possible without risking cognitive overload in the users (Allen, 2004). Instead a user-centered design is preferred. This assists the users, no matter their previous knowledge of radio astronomy and space, to be able to use the installation with as little friction as possible. The key is what Allen (2004) calls "*Immediate apprehendability on all scales*". It should be as easy and intuitive as possible to understand how to interact with and learn from an installation at a museum, even if said installation is made to provide a challenge for the user. However, designing an installation to strictly adhere to this principle may lead to an installation that does not stimulate the curiosity of the user. Instead Gutwill (2008) argues that a more open-ended design could be used to motivate innately curious and discovery-driven visitors.

This comes with a major flaw though. Making an installation too open-ended could make the user confused about what they are supposed to do or achieve when interacting with it. This in turn may scare them away from it and the subject it tries to teach them. As such, it would be reasonable to say that to optimally design an installation you need to consider both how intuitive it is while balancing that with how much freedom to explore it grants the users. Leaning too far in either direction may lead to it feeling too childish, excluding more advanced users, or too complicated, scaring away and excluding the less experienced users.

According to L. Li et al. (2020), positive emotional like happiness, enjoyment and interest have a strong influence on memory and learning. When people experience

positive emotions during learning or interaction, their brain stores the information more effectively, remembers it for a longer time, and has an easier time recalling it later. Therefore, when the experience is enjoyable, it becomes easier to remember, making the person retain the knowledge for longer, Sommer et al., 2008. Memory does not function independently though, but is influenced by emotions such as happiness and enthusiasm as well. As a result, emotionally engaging events become more ingrained in the memory than ordinary events without emotional involvement. This is because, according to Hamann (2001), emotions affect both the encoding and consolidation stages of memory formation.

In contrast, negative emotions such as stress, psychological pressure, and anxiety weaken memory. When a person is under continuous stress, the body releases the hormone cortisol, which negatively affects brain function, weakens thinking and memory processes, and reduces the ability to learn. In other words, excessive stress leads to poorer memory performance (L. Li et al., 2020). Based on this, it can be concluded that enjoyable and motivating prototypes or installations would be remembered for a longer time, while boring or confusing ones are forgotten more quickly. Enjoyable installations in exhibitions that aim to educate visitors are effective and powerful learning tools compared to those that are difficult to understand and visitors find less interesting. According to Wideström (2020), effective science center installations combine physical and virtual elements and encourage interaction, enjoyment, and user participation.

Thus it is imperative to explore the how to make an exhibition, or entire museum or visitor center for that matter, a satisfying and enjoyable experience for the visitors. Pekarik et al. (1999) defined four categories of satisfying experiences for visitors. Object experiences which focuses on things other than the visitor, possibly an example of an actual object if applicable. Individuals that prefer this kind of experience likely prefer to see the real thing instead of some incomplete representation of it, for example a real car instead of a model. Cognitive experiences are those that allows for the possibility for contextual clues and interpretations that allow individuals to draw their own conclusions based on the information given. Introspective experiences on the other hand are those that make the visitor look at their personal feelings and life. These thoughts could be triggered by objects or the ambiance of the area they happen to be. Lastly are social experiences that focus on the social aspect of an installation, this can vary from cooperation between two or more individuals to people spending time with their families.

What categories individuals preferred of these differed from person to person, however, the preferred experience by visitors to different museums generally tended towards one or another based on the type of museum. For example, it was found that in natural history museums the preferred type of experience was the object experience, with a strong secondary preference for cognitive experiences depending on the exact type of exhibition. It was also shown that one or two installations in a museum tended to stick out and be the most satisfying for the vast majority of visitors.

A study by Hein (2009) has shown that changing the formal environments for learn-

ing to informal environments benefits science learning. Therefore, moving a subject from schools to another place like sciences centers can enhance the students' learning, especially when the subjects or contexts are complicated, such as astronomy. Furthermore, by utilizing the appropriate category for satisfying experiences in museums in the installation's design it may be possible to increase the retention of knowledge and the experience of interacting with the installation.

To increase the chance of visitors spending time with and learning from an installation it is important that their attention is retained for an appropriate amount of time. Rounds (2004) lists a few "*Attention rules*" and "*Quitting rules*" that try to describe how visitors search for, attend to, and leave installations. These attention rules may be used to guide the design decisions to catch the visitors' attention, guide them through the experience of interacting with the installation by minimizing the required time investment, and come up with a satisfactory "solution" to whatever problem they may be faced with. At the same time it is important to reduce the chances of satisfying the quitting rules, as upon doing so the user may give up on the installation and leave. This is more difficult to achieve than fulfilling the attention rules, and to avoid them entirely is basically impossible. Thus designing the installation in such a way that it provides a satisfying experience (Pekarik et al., 1999) creates positive emotions in the user (L. Li et al., 2020) and retains their attention to a satisfying degree (Rounds, 2004) is paramount for a successful design.

Cesário et al., 2025 highlights the importance of involving experts when designing interactive exhibitions to make sure the information is accurate. If experts are not involved, there is a risk of misunderstandings, scientific mistakes, or oversimplifying the content too much. Radio interferometry is a complex concept, and if it is simplified without careful thought, visitors may develop an incorrect understanding of how it works. For LEGO ALMA, if astronomy and learning center experts are not involved in the design process, there is a risk of creating a system that teaches incorrect or misleading information. Therefore, co-design is a very powerful method that should be part of the design process to some degree to avoid delivering incorrect content.

However, tangible interaction has become more common in science centers and interactive learning environments. Unlike traditional screen-based interaction, which mainly relies on computers, screens, and computer mice, tangible interaction allows users to physically manipulate objects and interact through bodily movement in real space. According to Hornecker and Buur (2006), tangible interaction involves bodily interaction with physical objects and direct manipulation of material representations. They explain that tangible interaction can support playful exploration, collaboration, and social interaction while making interaction more intuitive and accessible for users. Hornecker and Buur argue that there is still a need for more research and understanding of how users interact with hybrid physical-digital environments.

In general, according to Claisse (2016), tangible interaction can create new ways for visitors to engage with installations. Combining physical and digital interaction can support "multi-sensory" which is involving more than one sense at the same time.

LEGO ALMA can be seen clearly as a tangible interaction installation in a science

center environment. Instead of only interacting through a screen, users physically place and manipulate LEGO antennas on an interactive table. Through this interaction, users engage with the installation using bodily movement and spatial interaction. The physical setup of the installation also supports collaboration and shared interaction between visitors. LEGO ALMA is therefore not only a digital educational tool, but also a physical and interactive installation that supports exploration, engagement, and embodied learning within a science communication context.

Also, according to Marchetti and Valente (2016), educational games for complex scientific topics should focus on a smaller set of core concepts instead of attempting to teach everything at once. Users can then understand these concepts through interaction, experimentation, and exploration. This idea is relevant for LEGO ALMA, where simplifying radio interferometry into a smaller number of understandable concepts may better support visitor learning and engagement. In addition applying this concept will open the door and encourage people to learn more about the educational topic in the future.

## 2.2 Ethical and Social considerations

This work aims to assist future interaction designers in the process of designing or re-designing installations in museums and science centers. The goal is to show how one can create or modify an installation to serve a wider audience with different capabilities and backgrounds, including scientists and children. It is important that an installation is as accessible as possible for the widest possible range of people (Heylighen & Bianchin, 2013). A design should not serve some users while excluding others, and the knowledge provided by the installation should be comprehensible by the widest possible audience.

Any design should consider users with less obvious disabilities, such as color blindness. However, it is important to note that it is nigh impossible to create an universal design that works for everyone. Thus, no matter how hard one tries, it is inevitable that some groups will be excluded. For example, users of LEGO ALMA with major visual impairments would be unable to utilize the current screen-based system. This limitation unfortunately makes the current design inaccessible to this specific userbase, something that will continue to be true with our re-design.

The main advantage of the current installation is that it helps visitors learn about radio telescopes and interferometry through tangible interaction. However, as it is generally inaccessible for most users we aim to figure out how one would improve it, and any other installation that suffers from similar problems. The findings of this project should hopefully help designers around the world develop more accessible and engaging tangible interfaces in the future, consequently increasing the science capital.

How the user tests are performed will vary depending on the stage the project is in. However, all participants in the tests are to be completely anonymous at all times. The testing of low fidelity prototypes are qualitative and consists of a short interview after the testing of the prototype. Participants will be recruited

though online forms, however, if the number that signs up is insufficient more will be recruited by recruiting passers-by. All participants will be provided with consent forms at the beginning of the tests informing them about what they will be doing, their right to quit the test at any time, and the fact that the test is completely anonymous. The data collected from these interviews will be stored for the duration of the project and deleted afterwards.

Tests of higher fidelity prototypes will be conducted using the LEGO ALMA installation and will consist of observations and conversations with visitors. The tests will be done during scheduled visits to OSO, mostly consisting of school classes with students aged 12-18, but also public study visits with more mixed groups. The visitors will be informed of the fact that tests will be performed during their visit ahead of time by the stakeholders. Because of this, the fact that no formal interviews nor surveys will be conducted, and that no personal information about the users will be collected, consent forms were deemed unnecessary. However, the visitors will also be reminded of the tests, and additional consent will be requested verbally at the start of the visit. Key points during the observations and conversations will be noted and used to develop the prototypes further.

Generative AI will see some use during this project. The purpose of this is to make the early stages of prototyping quicker and allow for the creation of higher quality low and mid fidelity prototypes. Anything created using generative AI will be clearly noted, either in the text, in a figure caption, or both. However, note that the final product will lack any content created by generative AI.

# 3

## Methods

Several methods will be used during the design process of the new LEGO ALMA prototype. The quality of the resulting prototype will depend on the methods used, how well they are understood and applied, and how suitable they are for the subject at hand. This chapter describes the methods and techniques that will be used throughout the project, how they work, and why they are appropriate for this work.

### 3.1 Research through design

Research through design, is an approach, usually using iterative prototyping, where knowledge is created by designing, testing, and improving interactive prototypes. The prototypes represent the design decisions made during the process, and based on how well they perform, help improve the next design iterations (Gaver, 2012). This not only helps with improving an existing design, but also gives the designers deeper knowledge about their users, possibly letting them avoid future fatal design flaws. As such, this has been deemed as the core technique to answer the research question at hand, and LEGO ALMA will be used as a testbed to provide these answers.

### 3.2 Rapid and Iterative prototyping

Rapid and iterative prototyping are design techniques that allows designers to quickly create prototypes early in the development process, test them, and iteratively improve them based on user feedback. This approach helps reduce both time and cost during the design process (Grimm, 2004, p. 130–134).

In the early stages of most designs, low-fidelity prototypes are commonly used. These prototypes are typically created quickly using simple materials such as paper and simple wireframes to communicate the overall concept of the design (Snyder, 2003, p. 3–8). Low-fidelity prototypes do not represent the final appearance or full functionality of the system but instead provide a high-level and abstract representation of the intended design (Hartson & Pyla, 2012, p. 396–397). Because they are cheap and easy to modify, they are effective tools for exploring and refining design ideas during the early stages of development.

For the redesign of LEGO ALMA, the intent is to create wireframes using both paper

and pen as well as digital tools. Wireframes are a powerful tool in the iterative design process because they help avoid focusing on visual details and sketching helps with brainstorming and ideation. While wireframes allow the designer to focus on general structure and interaction (Natarajan, 2025), sketching gives the designers ideas and ways to modify initial designs before any testing on large scale implementations is performed. These methods in combination helps outline the layout and feel of an interface before developing higher fidelity prototypes.

Additionally, this process of rapidly creating prototypes is interwoven with either quantitative or qualitative tests of each prototype iteration according to the iterative prototyping process. The exact type of test will vary depending on the stage of the prototyping process, as some prototypes may be better suited to certain types of testing than others.

Testing a low fidelity prototype with the Wizard of Oz method presents one limitation that may impact the results however. The person controlling the prototype may have some difficulty recognizing if the participant has interacted with the prototype, or if they do, not react fast enough. This can cause delay in providing feedback to the participant, destroying the illusion of functionality (Lim et al., 2008).

After testing the low fidelity prototypes to an appropriate degree they are followed by mid fidelity prototypes. These can be a lot more detailed, containing significant amounts of the core functionality in some ways, allowing for the designers to identify design flaws that were not apparent in the low fidelity prototypes.

When the LEGO ALMA project reaches this stage of development, Figma will be used for wireframing in order to create a mid fidelity prototype of the interface. Users will be able to see more details and high-resolution visuals on the screens that more closely resemble a completed product. Using a mid fidelity prototype before finalizing a design is crucial as it allows for the identification of issues related to the aesthetics, visuals, and interaction.

Lastly, the design developed throughout the prototyping process is implemented as a high fidelity prototype with a majority, if not all, of the intended functionality implemented. This allows for some last minute changes if something is identified as not functioning as intended. For LEGO ALMA at this stage this means that the design is almost complete. The final small details and high resolution graphics are applied to the prototype before implementing it in Python and the physical installation.

This method of rapid and iterative prototyping was determined to be the most efficient way to work for the purposes of this project. It allows for faster development of prototypes, and as a consequence, results being more rapidly produced in order to answer the research question.

### **3.3 Wizard of Oz**

The Wizard of Oz (WOz) method is a technique commonly used by interaction designers while testing prototypes. In this method a user tests a lower fidelity pro-

prototype with limited functionality. When the user interacts with the prototype, a researcher secretly changes it, making the user believe that their interaction influenced the prototype in some way. An example of this could be something changing on a screen when a button is pressed, even if the button is not connected to anything.

The WOz method allows for early testing with very rough prototypes and creates a collaboration between the users and designers (Molin, 2004). When the WOz method is used, users tend to be more eager to explore the prototypes without needing strict guidance. This may showcase flaws with a design that could be fixed early on in the design process, rather than discovering them later in higher fidelity prototypes that may be difficult to modify.

However, when using the WOz method it is important that the design is created with not only the user in mind, but also the researchers themselves, as well as the backend systems (Dow et al., 2005). Not doing so may negatively impact the test and the end product. The WOz method is highly reliant on the user's belief that the system is fully functional as mentioned by Taib and Ruiz (2007). If the user performs an action that requires more than one change the prototype, the prototype needs to be advanced enough to carry out the backend functionality. Thus, the researchers should be able to change multiple aspects of the prototype quickly to support any possible advanced interaction. This is to not destroy the user's belief in the prototype's functionality, and to preserve the integrity of the test.

Regarding this project working with LEGO ALMA, the WOz method has been determined to be the most effective supporting method to the rapid and iterative prototyping that will take place. This is because it allows for quick and easy testing of any prototype developed and identification of flaws in them.

### **3.4 Triple Diamond**

The triple diamond method is comprised of six phases – understand, define, sketch, decide, prototype, and validate (Marin-Garcia et al., 2020). A visualization of the method is also shown in figure 3.1. The purpose of the method is to provide a clear and structured path for interaction designers to follow when working with any kind of design.

Understanding the problem in phase one before proposing any solution is a very important step. It helps structure potential solutions in a clear way, and not doing this properly may have disastrous consequences down the line. The research process usually begins by reviewing related work to understand how others have faced similar problems, how the problem appeared, and how they attempted to solve it. This could be done by creating an understanding of the problem through user tests, where users opinions, thoughts, and impressions about the design is documented and analyzed. According to Hui et al. (2023), in the understanding phase, teams explore the background of the challenge, focusing primarily on understanding users and markets.

Defining the problem is the second phase and involves reflecting on the results gained

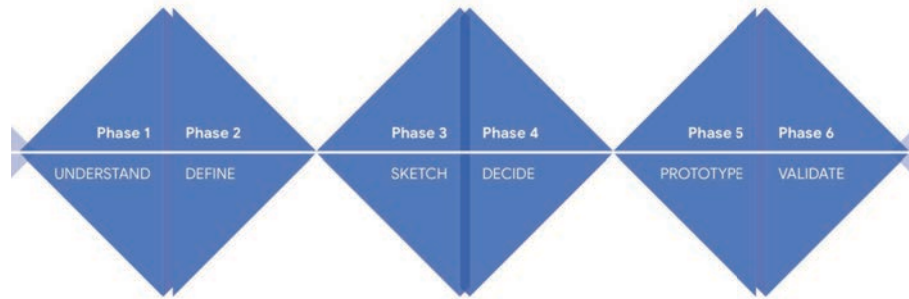


Figure 3.1: Image of the triple diamond design process

from understanding the users needs and identifying relevant issues. By the end of this phase, the main issues should be clearly defined in order to determine in what direction the project should proceed.

Phase three consists of brainstorming, generally by sketching, in order to generate an initial idea for a solution which will guide the work towards the final design. According to Van der Lugt (2005, p. 101), this is one way to use idea generation techniques, like brainstorming, and they are commonly used by designers in order to come up with any suitable idea.

The fourth phase consists of deciding what ideas to continue working with. In this stage the designers choose any idea they think has promise and could work well, as long as it fits the users' needs.

Phase five is when the prototypes will be constructed, low fidelity prototypes will initially be created, often in the form of wireframes, in order to move to the last phase. During the final phase the low fidelity prototypes are tested and evaluated. If one or more of the prototypes functions well with minimal problems it will be further iterated upon. This could mean that a higher fidelity prototype is made, or that attempts to improve the low fidelity prototype can be performed before continuing with higher fidelity prototypes. However, if none of the tested prototypes work then the entire process needs to be restarted as some critical error has been made along the way.

This method is ideal for the purposes of this project as it provides clear and structured ways of working with not only the prototypes, but also the process of answering the research question. It allows for quick identification of fundamental flaws in the work, and supports the other mentioned methods by giving them a place in the workflow.

# 4

## Design Process

### 4.1 Initial observations

To be able to redesign an installation with the purposes of making it more intuitive, accessible, and autonomous it is necessary to understand the starting point. Because of this the original design was studied and how users used the installation was observed to gain deeper knowledge into where it struggled.

#### 4.1.1 Installation design

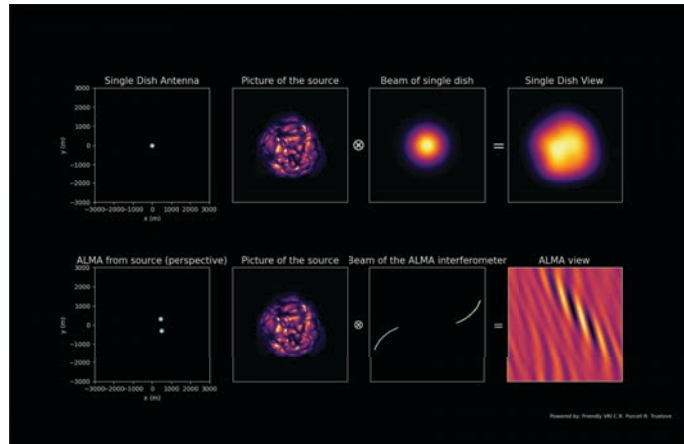
The installation can be divided into three main sections, the board, the buttons, and the screen. The board is the LEGO area consisting of two main components, the antennas and the sensors. The antennas are LEGO replicas of the antennas at the ALMA telescope with magnets in the base, and the sensors are flat, white LEGO bricks with magnets underneath to detect when an antenna is placed on top of it, see figure 4.1a.

The buttons are positioned between the screen and the board and consist of two sets of buttons. The first set is the one containing the four object buttons and is positioned right below the bottom left corner of the screen. The second set contains the three angle buttons placed below the object buttons and the screen with an arrow going from one button to the next. These buttons can be toggled on or off, but only one button in each of the sets can be toggled at a time and a button lights up when it is toggled. This means that only one object and angle can be selected at a time.

At the top of the installation is the screen which displays eight different graphs simultaneously as shown in figure 4.1b. The first row of graphs show what kind of image ALMA would produce using only one antenna, while the second row shows the image the current configuration of antennas on the board would produce. In each row there are four distinctly different graphs showcased. The first of which maps out the position of the antennas on the board. The second is a picture of whatever object is being observed at the time and the third is the beam of the telescope's interferometer. Finally, the fourth graph is the resulting image of the data the telescope gathers using the current antenna configuration. This resulting image will henceforth be referred to as the ALMA view.



(a) Image of the physical design of the installation.



(b) Screenshot of the installation's screen.

Figure 4.1: Image depicting the LEGO ALMA installation at Onsala space observatory.

### 4.1.2 User observations

Before the initial observations, the stakeholders shared their own thoughts based on what they had observed during prior visits to the visitor center. According to the stakeholders, the installation was missing clear guidelines, which often confused users about the purpose of the installation and consequently being reluctant to interact with it. Additionally, the stakeholders also mentioned how the installation was designed by astronomers for astronomers. This made it difficult for people outside this specific user group to understand and learn from the installation, something they wanted to change.

These stakeholder observations were later confirmed during our first observation session. Because of this, we created an instruction sheet for the installation designed in Adobe Photoshop and printed on A3 paper to place beside the installation before conducting a user test, shown in in appendix A. One stakeholders assessment of these instructions was that they served as a good starting point. However, based on their experience, they believed that many visitors would not read the instructions, as this behavior was common in the visitor center. Visitors prefer to discuss and explore the installations together with a guide if one is present, rather than explore on their own. This results in most visitors not reading the instruction even if they are readily available.

## 4.2 General plan

After observing and interacting with the LEGO ALMA installation, a general plan was created to initiate the redesign process in order to answer the research question. Additionally, an initial project timeline was laid out in order to approximately

structure the required work and tasks. See appendix B.

Different technologies planned to be used for the redesign of the installation include 3D printing for prototype testing and software development using Python. Additionally, Adobe Photoshop (Knoll, 1989) will be used to create images and animations for the project. Furthermore, wireframing will be used to develop and test screen prototypes and identify potential accessibility issues. Figma (Dylan Field, 2012) will be used as the wireframing tool.

### 4.3 Stakeholder interviews

As a part of the design process, formal interviews with stakeholders were conducted at the learning center. The aim of the interviews were to understand how the visitor center currently functions, which challenges visitors face, and how the visitor experience could be improved, with a focus on LEGO ALMA. The two stakeholders we interviewed were Robert Cumming, who works as an astronomer and science communicator, and Daniel Rosqvist, who works as an exhibition designer and engineer. Both of them gave useful insights, but from different perspectives.

Daniel was of the opinion that the main goal of the visitor center is not to teach visitors a lot of complex scientific information, but instead to make science appear more interesting and accessible. He also felt that the center's main purpose was to increase the science capital in the general public, and especially in younger audiences. According to Daniel, the center mainly focuses on younger visitors, around 10 to 15 years old. According to him, success is not about how much people learn during the visit, but whether they leave feeling curious and interested in science.

Robert Cumming also talked about the challenges they face with the exhibition. One major challenge is that the visitor center has a very mixed audience like children, adults, elderly individuals, and even scientists. Because of this, it is basically impossible to create a universal design that works well for everyone. He explained that some installations, like the drawer installation that showcases the size difference between different objects, are not easy to understand without help from staff. This tells us that the current design sometimes depends too much on verbal explanations instead of allowing visitors to explore by themselves.

Both Robert and Daniel had thoughts about the LEGO ALMA installation. They agreed that it is an important installation to the center, but its current design is too complex for most visitors. Daniel said that the system should be simplified so that more people can understand it without a guide. He suggested including different levels of difficulty into the design, so beginners can start with something simple and explore the more advanced concepts later. He also mentioned that the interface should be intuitive and easier to use, and that adding sound or guided instructions could help visitors more easily understand what to do.

Robert pointed out that the installation often needs a staff member to explain how it works. This is a problem because the goal is for the visitors to interact with the system on their own and not need a guide. If the installation cannot be understood

without help, this suggests that the design has not yet fulfilled its intended goal. He also mentioned that there are similar installations in other countries, such as a university or science center in Vienna and the European Southern Observatory (ESO). However, these are often used alongside guides and scientists who can explain them to visitors. This shows that creating an understandable installation that works for most people is very challenging.

Another important point mentioned by the stakeholders is that the goal is not to give complete scientific explanations, but rather to create curiosity. Daniel Rosqvist was of the opinion that the most important thing is to let visitors feel interested and want to learn more later. This aligns with the informal education concept, where people learn through interaction and exploring on their own.

From these interviews, we got a good understanding of the problem that LEGO ALMA is facing and that the main problem is not the scientific content itself, but how it is presented. The design needs to be clearer and more intuitive so that visitors can use it without a guide. It should also give clear feedback so users understand what is happening when they interact with it. At the same time, it should support different types of users, from beginners to more curious visitors who want to explore the concepts more. Most importantly, the design should focus on creating an engaging experience that encourages exploration, instead of trying to explain everything directly.

Thus, from these interviews, we can define several important design requirements. There needs to be clear instructions available to the users to make interaction with the installation more accessible without external guidance. The design needs clear user feedback in the form of audio, video or both to support users with any level of experience. Finally, the installation should be modified with a focus on exploration instead of direct explanation by reducing the amount of information immediately available to users. The stakeholder interview questions can be found in appendix C

### 4.4 Field study

In the middle of February we did a study visit to Universeum in Gothenburg (Universeum, 2023). The purpose of the visit was to observe how visitors moved, what installations they interacted with, if they understood the installations, how they felt, and if any installation stood untouched for an extended amount of time. These observations were accompanied by hands-on experimentation with the installations to further understand them and see what makes them function better or worse.

During the visit we focused on the areas focusing on the human body, mathematics, and space since their purpose is very similar to that of OSO's visitor center. The sections obviously had parts that both struggled to grab and retain the visitors' attention and those that had a really easy time doing so.

One installation that really succeeded in grabbing and retaining the visitors' attention was the one focused on the human skeleton as shown in figure 4.2. This installation had both elements of play and competition in the form of timers keeping track

of how long one can dead hang in the bars suspended from the ceiling. This made it engaging for visitors of all ages to interact with and explore this installation. We never observed any visitor having any issues understanding the installation. However, it was noted that especially younger children had problems interacting with it as the bars you are supposed to dead hang in are quite high up.



Figure 4.2: Image showing the installation showcasing the human skeleton.

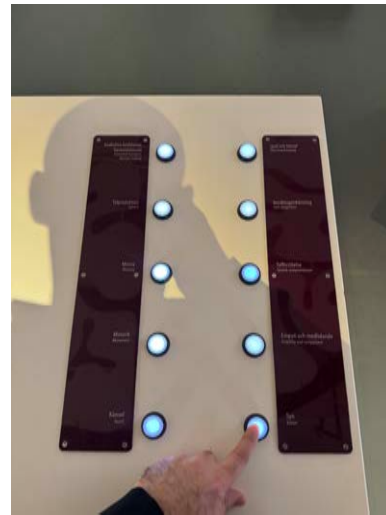
Another installation of note was one that didn't get much attention from visitors. This one was dedicated to the human brain and which parts of it were responsible for different functions, see figure 4.3a and 4.3b. It served as a really good example of how to communicate concepts that seem complex on the surface in an easy and approachable way. The installation consisted of a depiction of the brain hanging on a wall and ceiling, and a set of ten buttons. When a visitor pressed one of the buttons a lamp on the brain depictions would light up, creating a clear connection between a certain action and what part of the brain is used for it.

However, there were also installations that we noted to have obvious flaws that caused friction during interaction. One of these installations was a set of screens distributed around the sections. These screens contained quizzes asking varying area-appropriate questions, an example of which can be seen in figure 4.4. The screens didn't have any major issues that hindered their usage individually, however, collectively they had a large flaw. This problem was that the screens' interfaces differed slightly in design from one to the next. This creates a clear point of confusion when moving between screens where the user has to figure out a new interface each time.

Another installation with a clear flaw was the wall whose aim was to showcase the endocrine system, part of which is shown in figure 4.5. While the idea behind the installation is sound the execution leaves a lot to be desired. The user is asked to press a button to the left or right of a cutout of a male or female body. When a button is pressed a lamp would light up on the cutout of one or both of the bodies to show where in the body the corresponding organ is located. However, the big



(a) Photograph of the vertical slice of the brain, showing both highlighted areas and lamps.



(b) Photograph of the buttons used to light the lamps on the depictions of the brain.

Figure 4.3: Images of notable installations in the human body section of Universeum

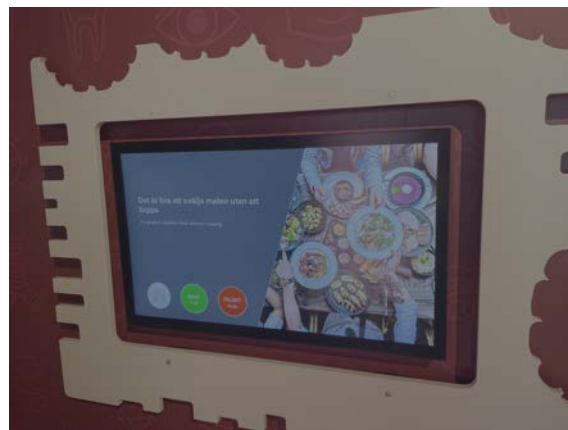


Figure 4.4: Image showing one of many quiz-screens placed around the body section of Universeum

problem with this design is that it is very easy for a user to miss the lamp lighting up when they click the button. The main reason we identified was that the user would need to both keep pressing the button and turn and look at the cutouts of the body to see the lamp, something that rarely happened during our observations.

Lastly there was one problem that a majority of installations in the mathematics area had. As showcased in figure 4.6, a lot of installations in this section had a tendency to overload the user with information in the form of long paragraphs of text, written in small font sizes. Based on the lack of visitors reading these, especially among the younger audiences, our observations suggest that these large blocks of text are either not interesting or as attention grabbing as more interactive installations. This was particularly evident with the installation shown in figure 4.6b as we never saw a single person read the text on the wall and instead all of their focus was on the



Figure 4.5: Photograph depicting one half of the installation showcasing the endocrine system at Universeum.

interactive screen next to it.



(a) Photograph of the *Hands on* installation in the mathematics section.



(b) Photograph of the installation showcasing the golden ratio in the mathematics section.

Figure 4.6: Images depicting two different installations in the mathematics section at Universeum.

## 4.5 Ideation

To start the redesign of the LEGO ALMA installation an ideation session was held. During this ideation session, 14 ideas with some promise were generated. Each idea was developed for approximately ten minutes and can be found in appendix D. The

ideas were discussed to ensure a mutual understanding of their concepts. After the discussion, the ideas were evaluated and voted upon to identify the most promising ones. This was done with the aim of later combining the most promising elements from each one into one final idea. This final idea was then visualized through a higher fidelity sketch, as shown in figure 4.7.

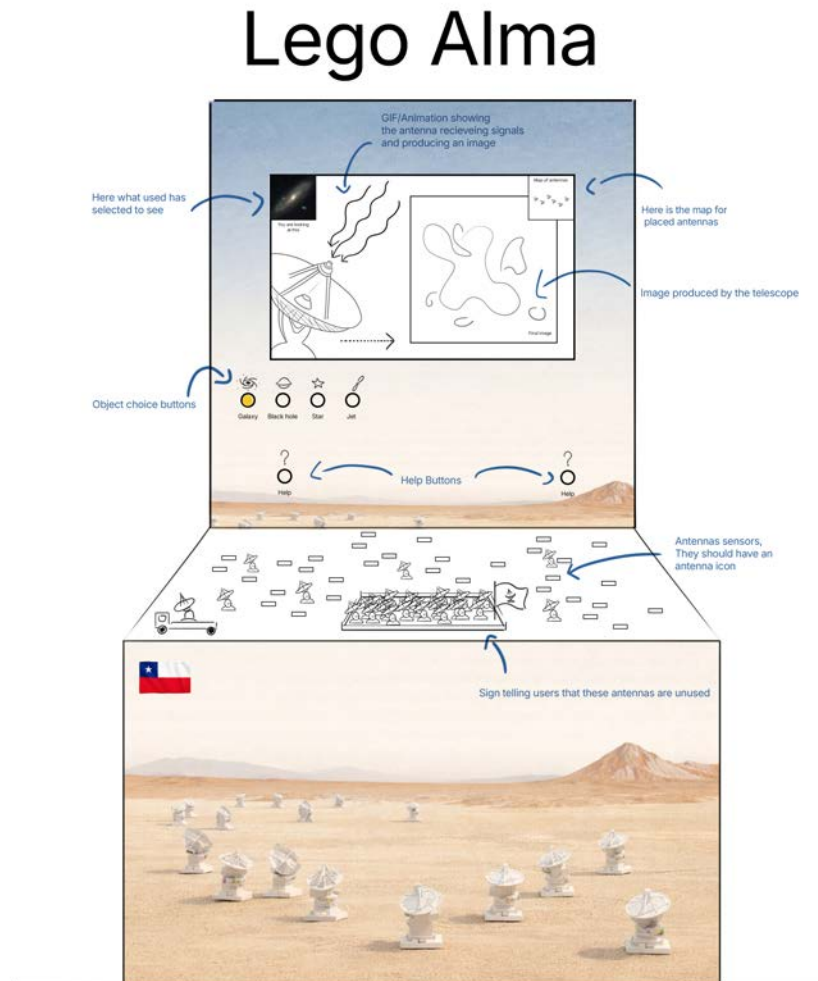


Figure 4.7: An illustration developed to present our initial idea for the installation.

The idea was then presented and discussed with the stakeholders at OSO. The idea of including the Chilean flag on the side of the table was rejected. Though ALMA is located in Chile, it was built through a collaboration between many countries. Therefore, including all participating countries' flags would likely introduce unnecessary visual complexity. Because of this, the stakeholders suggested not including any flags in the design.

## 4.6 Testing Procedures

Repeated prototype testing is an important part of designing systems intended for public use. In the case of LEGO ALMA, the primary user group happens to be school aged children which means that both mental development, technical skill, and levels of curiosity will vary a lot. Because of this it is important to use testing procedures that fit both the age group and the environment the tests are performed. Thus, depending on what level of fidelity a prototype is and who it is tested on, different testing procedures might be necessary.

### 4.6.1 Low fidelity prototype testing

To test the low fidelity prototype an invitation was sent to students in the Game Design and Interaction Design programs at Chalmers University of Technology through Discord. A Doodle poll, an online scheduling tool for booking and organizing meetings Doodle, 2026, was used to organize participant sign-ups. The invitation described the purpose of the user test and included a brief introduction to the thesis project. Three students signed up for the user test using this method and booked a time slot for participation. Additionally, three other students were invited verbally to participate in the user test. After accepting they were provided with a link to the poll and booked a time slot for participation. Furthermore, an expert participant and mentor from Ghostar (Ghostar, 2026) was informally invited to participate in the user test in order to gain broader feedback on the low fidelity prototype and increase the number of participants.

During the tests we defined two roles. One researcher introduced the prototype and conducted the interview, while the other documented participant responses and observations.

At the start of the test, each participant was provided with a consent form, see Appendix E. The participants were required to read and consent to the conditions stated in the consent form before starting their testing session. An additional brief explanation of the prototype and its elements was provided to the participants before the testing started. When the tests concluded the participants were asked a set of interview questions, after which they were asked to freely share their opinions and feedback on the prototype.

### 4.6.2 Mid fidelity prototype testing

The mid fidelity prototype was tested at the OSO visitor center using the original physical installation while replacing the content displayed on the screen with our prototype. The prototype was tested with a variety of visitors, primarily consisting of schoolchildren aged 10-18 years old.

It is important to note that in both the mid and high fidelity prototype stages, the participants parents were informed about the testing sessions by the stakeholders a few weeks prior to the visit to the visitor center. Additionally, an introduction

to the project and the study was presented to the participants at the visitor center before the testing sessions began. During the testing sessions, photography of the participants was not permitted, and this was respected throughout the testing process.

A combination of observational user testing, informal interviews, and the Wizard of Oz method was used during the testing of the mid fidelity prototype. The user test process was divided between the two of us. One of us was tasked with subtly changing the UI in the prototype based on what the participants were doing with the installation at the time. Meanwhile, the other person observed and documented the participants behavior and reactions during the session. Additionally, the participants were asked several informal questions about the installation. This was done in order to evaluate whether or not the goals of the prototype had been achieved and to better understand their opinions and thoughts on the experience.

### 4.6.3 High fidelity prototype testing

To test the high fidelity prototype the same observational testing approach used in the mid fidelity stage was once again used. However, during these tests the installation was left on its own without anyone nearby to guide the users. Observations were made from a distance and were mainly in regards to how the users interacted with the installation and to document issues and reactions. This was done with one goal in mind, to see how well the installation functioned on its own without a guide.

## 4.7 Low fidelity prototyping

The first low fidelity prototype consisted of two main parts; a physical setup placed on a table and a digital interface on a screen, as shown in figure 4.8. The physical part of the prototype was created using simple low-cost materials such as paper, pens, printed images, and laser-cut wood. These elements represented the buttons, antennas, and the LEGO table from the original LEGO ALMA installation at OSO. The buttons were drawn using paper and pen and a green circle made from paper was used to indicate the selected button. The antenna disks were made from paper, and the stands were created using small laser-cut wooden pieces.

Only eight antennas instead of 44 were created to allow for faster prototyping and quicker testing. A picture of the LEGO table at OSO, where the LEGO antennas should be placed, was taken and modified using Adobe Photoshop to represent the table in the low-fidelity prototype.

A computer displaying a wireframe prototype was used to show the digital interface. The view on the screen consists of three sections. The first is the selection view, as shown in figure 4.9. While on this screen the user can select an object by clicking one of the four physical buttons available to them. The four options to choose from are the Galaxy, Black Hole, Star, and Astrophysical Jet. The images shown for these objects were created with generative AI to save time. After clicking a button the green circle will be placed on it to simulate that the button has been pressed

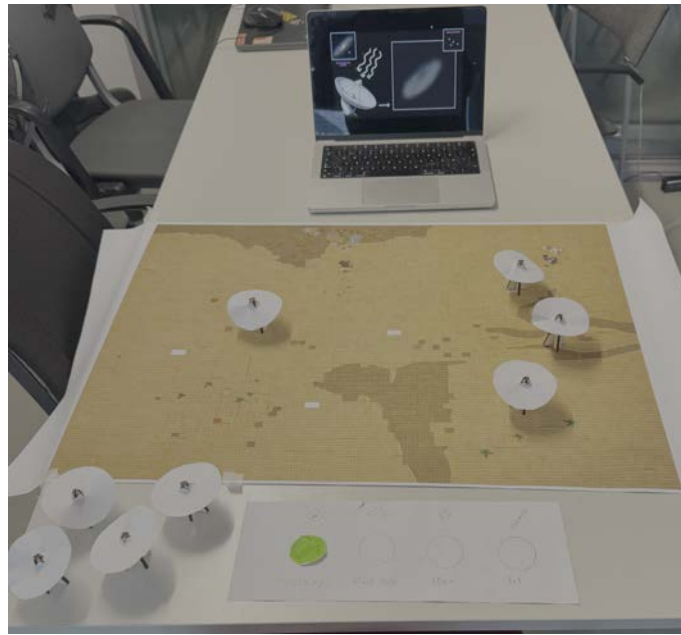


Figure 4.8: Image of the low-fidelity prototype

and the view on the screen will change.

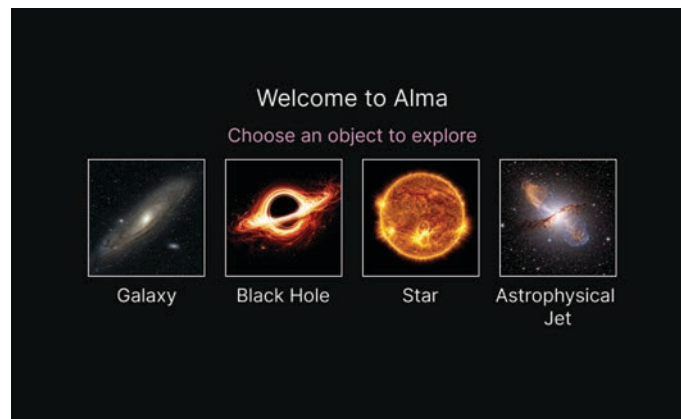


Figure 4.9: Selection view of the low-fidelity prototype

The next view the user sees is the guide view showing an animated request which asks them to place an antenna on any of the white sensors on the board, see figure 4.10. After placing one or more antennas, the view on the screen changes to the observation view, as shown in figure 4.11. Depending on how many antennas are placed on the white sensors, the displayed image in the largest frame on the screen gradually increases in detail.

In the top left corner of the observation view there is a reference image showing the final result that users should see after placing all antennas correctly. In the top right, there is a map of the LEGO table that shows how many antennas have been placed on the white sensors through the number of antenna icons that are visible.

The large image of an antenna in the bottom left corner, as shown in figure 4.11,

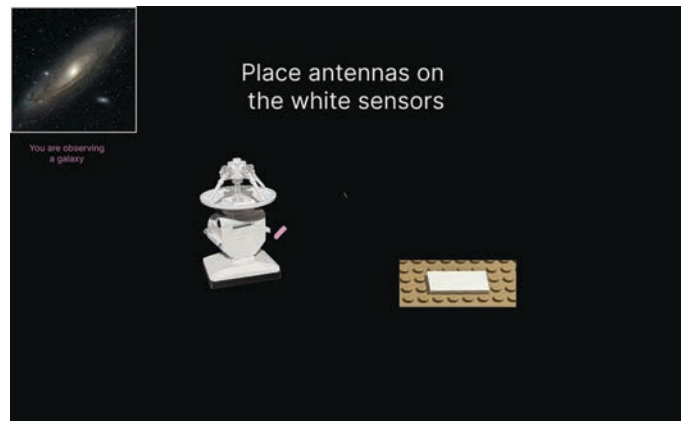


Figure 4.10: Request to place an antenna on any white sensor

represents how the antennas receive data, which is then processed by a computer and transformed into an image. The aim of this animation is to explain in a simple way how the antennas work. However, it is important to note that the antenna itself was generated using AI to save time and further enable rapid prototyping.

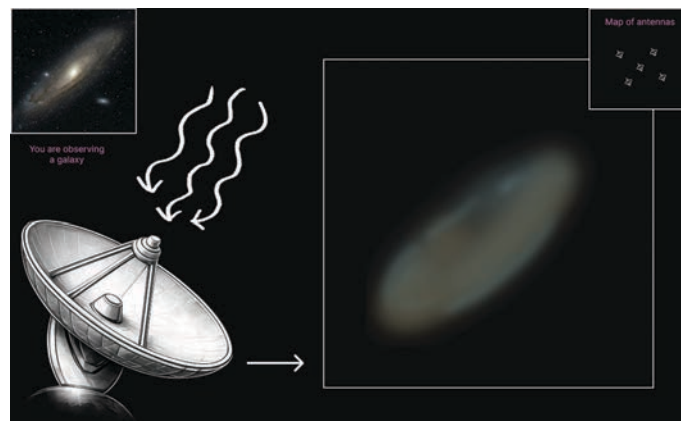


Figure 4.11: Image of the observation view for the low fidelity prototype

This first prototype was tested with six students from the Game Design and Interaction Design programs at Chalmers, as well as an external mentor from Ghostar Ghostar, 2026 (an AI and e-commerce consulting agency). The aim was to gather feedback from both users' perspectives and a domain expert's perspective in addition to getting a feel of how the idea would be received in general. The results showed that several aspects worked well, while others need improvement to better align with the installation's aim.

The following points summarize what parts of the prototype worked well:

- Reducing complex visual information in the UI increased user curiosity and encouraged participants to ask more about the topic afterward.
- It was easy to reach the physical buttons because they were positioned close to the participant.

- Participants could easily switch their attention between the prototype's screen and the LEGO table because both were positioned in close proximity and in line of sight.
- The welcome screen was clear, and it was easy to understand what to click in order to choose an object to observe.
- The request to place an antenna on a white sensor was clear and understandable.
- The antenna map was easy to understand.
- The reference image in the top left corner was easy to understand.
- The illustrated white antenna, which showed how antennas work, was easy to understand.
- That the final image should be similar to the reference image.

However, some things did not work as well as intended. The black hole that was used instead of the protoplanetary disk because the disk was deemed to be too similar to the galaxy received criticism from one of the stakeholders. This was because ALMA is not designed to observe black holes on its own, while protoplanetary disk is one of the main things it observes.

Several other aspects of the design were found to be unintuitive. For example the placing of antennas. It was not clear that multiple antennas should be placed on the board. Some participants thought that only one antenna should be placed, even though the instruction stated place antennas on the white sensors. Some participants missed the placement instruction entirely due to placing an antenna before clicking a button, causing the guide view to be skipped entirely. Furthermore, even if the participant realized that they were supposed to place more than one antenna, there was little to no motivation to do so as the final image was already displayed in the top left corner of the screen.

One major aspect of the antenna placement that was missed by the participants because of a limitation of the prototype was the impact spreading and gathering of antennas is supposed to have. As this was too complex to implement in this stage of prototyping it was skipped when creating the prototype.

Lastly, it was determined that the antenna map did not provide the participants with additional, useful information. This, as well as the fact that the antenna image in the bottom left corner drew too much of the participants' attention, meant that these parts of the design needed to be adjusted in some way.

## 4.8 Mid fidelity prototyping

The mid fidelity prototype used the existing LEGO ALMA installation at OSO together with external prototyping tools to make a prototype that was possible to test at the visitor center. The user interface on the screen was replaced with our own UI, which was created in Figma, in order to test and iterate on our design

solution before moving to the high fidelity prototype and developing the final UI using Python. The aim of this was to save time in the later stages and to allow for potentially quick improvements after conducting user tests. In total, four mid fidelity prototypes were created and after testing each prototype, they were iterated upon to address what was missing or unclear in the previous version.

In this section, we briefly present all four mid fidelity prototypes, explaining their differences and the results from user testing. Additionally, descriptions of how the prototypes were developed and how they were tested are also provided here. For a complete view of the final mid fidelity prototype see appendix F.

### 4.8.1 Prototype 1

The first mid-fidelity prototype was based on the low-fidelity prototypes interface. However, all views were revised to some extent. In the selection view, the second object available was changed back from a black hole to a protoplanetary disk based on stakeholder feedback. The image in the top left corner of the guide view, which displayed the selected object, was removed. Finally, the reference image and antenna map were removed from the observation view in an attempt to increase the users' curiosity and reduce the amount of unnecessary information on the screen. Instead, the interface displayed the number of antennas on top of the ALMA view in an attempt to provide clear feedback to the user, see figure 4.12. Furthermore, the antenna image was significantly reduced in size and the placement animation was added to the observation view to encourage users to continue placing antennas.

The ALMA view images were re-drawn with 44 unique frames instead of the eight used for the low fidelity prototype, to match the full number of antennas in the installation, see figure 4.12. The reason for doing this is that the ALMA view created in the original design could not be used in combination with Figma. The system generates its images dynamically based on the exact positions of the antennas, making the act of reusing them in the prototype impractical.

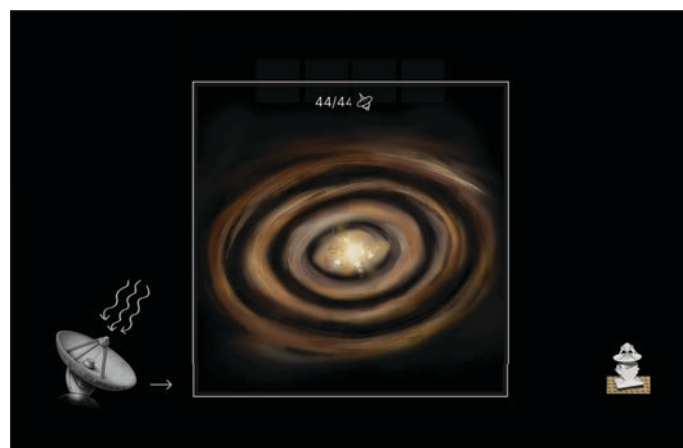


Figure 4.12: Image of the first mid fidelity prototype's observation view.

The prototype was tested with children approximately aged 11-12 years old. Although it worked well, the following issues were noted during the user test:

- The participants immediately interact with the LEGO elements on the board while ignoring the screen.
- It was unclear where participants should click in order to access and explore the different objects.
- The observation view did not reflect differences in antenna placement. As a result, users were not encouraged to experiment with distributing the antennas on the board in different ways to achieve different image qualities.
- When the number of antennas equals the number of sensors, users could not meaningfully explore different antenna distributions anymore.
- It was not clear how close to the perfect image the user was after placing all antennas.

### 4.8.2 Prototype 2

Two additional interface views were introduced in the second mid fidelity prototype. A video view showcasing the original ALMA radio telescope was added to attract visitors attention when the installation was idle. Whenever a user pressed any of the buttons below the screen the video would stop and the system navigate to the selection view, see figure 4.13a.

However, if there were any antennas on the board's sensors when the button was pressed, the second new view would be shown. This view is the reset view and as its name suggests, tells the user to reset the installation. The reset view displays an image on the screen telling users to move all antennas currently on the board into the storage area, see figure 4.13b. However, only four antennas were shown in the storage area in the image, as adding all antennas to the image would be too visually cluttered. A short descriptive text was also added to support users' understanding of the image. Once no antennas remained on the sensors the system would navigate to the selection screen. This reset view was also displayed after the installation perceived one minute of inactivity.

In the selection view, a pink arrow pointing towards the object buttons was added. This was in an attempt to help the users locate the buttons as they had a hard time finding them in the first mid fidelity prototype iteration.

In the observation view, the positions of the antenna image and the placement animation were switched. The antenna image was moved to the right side of the screen, while the animation was moved to the left, see figure 4.14. The aim of this change was to create a more natural interaction flow. A user places an antenna, the ALMA view is updated, and finally the user is shown how the antennas work through a simple explanation of how the ALMA view image is produced.

A progress bar was added below the ALMA view and two scenarios were defined. First, if the antennas were placed close to each other and not spread across the LEGO board, the system displayed a maximum of 50% image quality. Second, if



(a) Image showing the video view added in mid fidelity prototype 2.



(b) Image showing the reset view added in mid fidelity prototype 2.

Figure 4.13: Photos from the LEGO ALMA installation interface in mid fidelity prototype 2.

the antennas were widely distributed, the system produced the best image quality, reaching 100% (see figure 4.14).

As the previous prototype iteration showed, there was no intuitive way to show how spreading and gathering the antennas on the board would impact the ALMA view image. This was because all 44 antennas were available which would lead to all sensors being covered, removing the possibility for other antenna configurations. To address this, half of the antennas were removed from the installation, resulting in a total of 22 antennas instead of 44. This, combined with the two different max values on the progress bar, aimed to encourage the users to experiment more with how they place the antennas on the board.

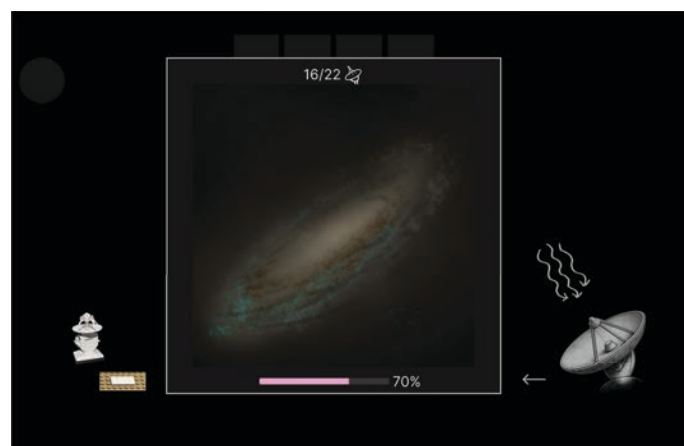


Figure 4.14: Image of the screen for the antennas view in the second mid fidelity prototype

The prototype was tested with students from grade 9 in elementary school (aged

15-16). The prototype functioned well overall but the following issues were noted during the user tests:

- Participants were still ignoring the screen in favor of the board when first approaching the installation.
- The video did not draw the participants attention to the screen.
- The text under the video, which asked participants to click any button on the installation to start, was ignored.
- The installation's built-in speakers are barely audible even when set to maximum volume.
- The digital button did not have the same color as the physical buttons below the screen, confusing the participants.
- The arrow pointing to the physical buttons on the selection view did not effectively help users understand where they should click.
- The reset image was not fully understood. Some participants believed only four antennas needed to be moved rather than all of them.

### 4.8.3 Prototype 3

Additional changes were made to the mid fidelity prototype for the third iteration. In the video view, the text at the bottom of the screen was highlighted by increasing its font size and adding a solid white background with a dashed outline to it. This was done to increase the amount of attention the text would pull by improving its visibility and readability. Additionally, a color closer to the one on the installation's physical buttons was applied to the icon next to the text, see figure 4.15.



Figure 4.15: Image of the video screen for the third mid fidelity prototype

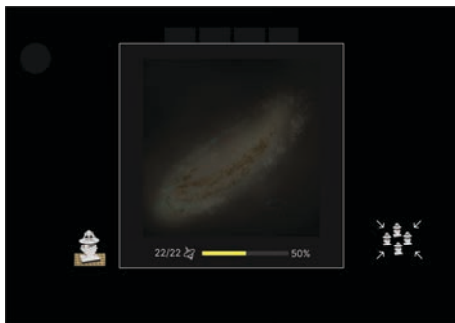
In the reset view, the reset image was replaced with an animation image. The aim of this was to clearly communicate that all antennas, not only four, should be removed from the board. The animation sequentially shows groups of three antennas being moved into the storage area on the board in a looping sequence in order to

emphasize that all antennas must be moved. Additionally, the word ALLA (meaning all in English) in the text above the animation was made bold and highlighted in pink to attract more of the users attention.

In the selection view, three additional arrows were added in the bottom left of the screen, pointing towards the physical buttons on the installation. This was done because the arrow from the previous iteration of the prototype was deemed too difficult to see even though it worked whenever it was spotted.

In the observation view, the antenna image on the right side of the screen was removed. The reason for this change was that it was determined that explaining how individual antennas work is not part of the installation's purpose. Furthermore, it is difficult to clearly explain how the final image is produced from the collected data. Because of this the image was replaced with an animation that attempts to encourage users to experiment with antenna placement instead. The animation attempted to tell users to spread or group the antennas on the board without explicitly stating it, as shown in figure 4.16.

For this iteration rudimentary sound feedback was also implemented. This was in the form of audible feedback when placing antennas on the sensors and the audio from the video view of the installation. The issue with the low volume in the installation's internal speakers was solved by using two external speakers instead. These speakers were placed on top of the installation, directly above the screen in an attempt to draw users' attention away from the board and towards the screen.



(a) The observation view for LEGO ALMA when users are grouping the antennas on LEGO table.



(b) The observation view for LEGO ALMA when users are spreading the antennas on LEGO table.

Figure 4.16: The observation view for LEGO ALMA in the third mid fidelity prototype.

This iteration of the mid fidelity prototype was tested with students in third grade of high school (aged approximately 17-18). Although some unsolved issues from earlier iterations remained, the prototype generally succeeded in meeting its design goals. The problems identified in this prototype are the following:

- The animation intended to guide users to spread or group the antennas was unsuccessful and confused some participants.

- The audio feedback for placing antennas on the sensors was too loud and disturbing.

#### 4.8.4 Prototype 4

This was the final iteration of the mid fidelity prototype, and several things were changed, mainly focused on the observation view. The animations for placing antennas and for spreading and grouping antennas in the observation view were altered slightly. When users initially navigate to the observation view after selecting an object, only the antenna-placement animation is shown, see figure 4.17. After the first antenna is placed, this animation is hidden and replaced with an animation telling them to either spread or group the antennas. The displayed animation depends on the current antenna configuration on the board and may change as more antennas are added. If users choose to gather the antennas the ALMA view image will not exceed 50% resolution. In this case, the animation encouraged users to try spreading the antennas instead, see figure 4.18b. Similarly, when users spread the antennas, the animation tries to encourage them to try grouping the antennas instead, see figure 4.18a. This approach aims to encourage exploration by prompting users to experiment and observe how their choices affect the result. Furthermore, this change was also made to reduce the visual complexity of the observation view and help focus the users' attention on one action at a time.

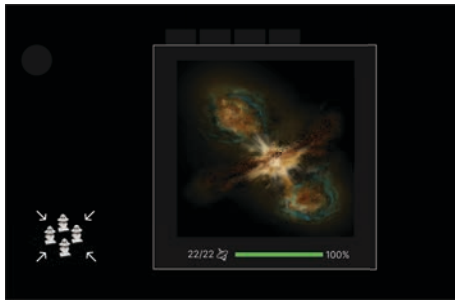


Figure 4.17: The observation view for LEGO ALMA when users place only one antenna on white sensors.

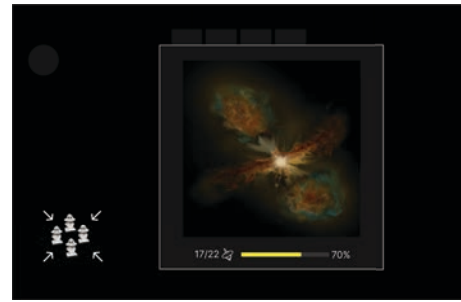
Finally, the audio feedback used when placing antennas was replaced. This was done as the previous sound was deemed too disturbing for the rest of the exhibition.

This iteration of the prototype was tested with students from grade 9 in elementary school (aged 15-16). The prototype achieved its intended goal, though areas that require further refinement were still identified. The following issues remain unresolved:

- The sound used for the audio that plays when placing antennas needs to be changed.



(a) The observation view for LEGO ALMA when users are spreading the antennas on white sensors.



(b) The observation view for LEGO ALMA when users are grouping the antennas on white sensors.

Figure 4.18: The observation view for LEGO ALMA in the fourth mid fidelity prototype.

- The animations for spreading and gathering antennas were still hard for participants to understand and they could not clearly perceive the difference between the two actions.

## 4.9 High fidelity prototype

The high fidelity prototype was created to evaluate how well the mid fidelity design functioned independently. This would allow for a deeper understanding of the project’s design choices to be gathered. How easy were the animations to understand? Could the users navigate the interface to a reasonable degree without getting lost, confused, or frustrated? Were there any parts of the design that the users skipped or missed? Why?

Only one high fidelity prototype was developed. However, small changes were made to try to draw more attention to, or amplify, the effectiveness of certain parts of the design. The prototype was code-based and developed using the Python programming language as that was what the original installation used. This further allowed us to use the original code as a backend to our design and allowed us to just grab the parts needed for re-use in our new design.

Since our mid fidelity prototype was made using Figma, and the new high fidelity prototype was developed in Python, we had to figure out some way to convert a wireframe prototype to functional Python code. This challenge was solved using the program TkForge (“TkForge - made with Wegic — tkforgepython.wegic.app”, 2023) which allows for limited Figma designs to be converted into python code.

Due to time constraints, system conflicts, and limitations because of the way the system was programmed some aspects of the mid fidelity prototype’s design needed to be discarded or changed. This was in order to get the high fidelity prototype working in time for testing. Some of these aspects included, but were not limited to:

- Certain interface elements in the views being entirely removed or not animated.

For example, the arrows in the selection view not being animated and the button icon in video view being removed.

- The video view’s video lacked audio.
- The ability to view the result of only having one antenna on the board being removed.
- The ability for the progress bar to show the detail level of the ALMA view based on antenna number and configuration.
- The observation view’s progress bar changing color based on image quality.

However, some things that were not possible to implement or do well in the mid fidelity prototype were possible to implement in the high fidelity prototype. Some of these include the following:

- The ALMA view picture changing dynamically based on antenna positioning.
- Increased accuracy of audio feedback when antennas were placed on the sensors.
- The responsiveness of the system being significantly increased and reduced system lag.
- The system automatically resetting after a set time of inactivity.

Together, these improvements resulted in the high fidelity prototype’s design remaining close to the mid fidelity visually, but allowed for it to be a fully autonomous system. Complete screenshots of the high fidelity prototype can be found in chapter 5.

### 4.9.1 Testing

The high fidelity prototype was evaluated over three testing sessions with 9th graders (aged 15-16). Compared to the mid fidelity testing sessions, one main difference was introduced. During these tests we were not close to and actively helping the participants use the prototype, something which was unavoidable for previous prototypes. Instead we observed from a distance to see how well the design would function independently.

The tests showed us that the high fidelity prototype was generally successful, although several issues that were identified in the mid fidelity prototype were still there. However, this is to be expected as the general design was not revamped for the high fidelity prototype. Furthermore, there was an issue that appeared in the high fidelity prototype that had not been considered in earlier prototypes due to it being based in how the installation was originally designed and programmed.

This issue was specifically in regard to the physical buttons’ implementation. The buttons were programmed so that one of the object buttons and one of the angle buttons were always toggled. If participants pressed an already active button nothing would happen, causing occasional confusion and making them believe that they

did something wrong.

However, the biggest issue that transferred over to the high fidelity prototype from earlier prototypes was that the users did not start off by looking at the screen. Instead most users gravitated towards the board and started distributing the antennas on the board before they were supposed to do so, unintentionally ignoring the screen. This is something that needs to be solved for the installation to reach its full potential.

Another problem that was still prevalent in the high fidelity prototype was that the animation intended to inspire the user to experiment with their antenna placement was still largely unsuccessful. One important observation was that the participants repeatedly overlooked the animation in the bottom left of the screen entirely. Because of this a change was made to the prototype between test session one and two, a background was added to the animation to make it more visible and a text was added to support it, see figure 4.19. This change was considered necessary since even if the participant noticed the animation, they generally did not understand it. The aim of this was to try to make it easier for the users to both see and understand the animation as well as to promote more experimentation with the installation.



(a) Original version of the observation view.



(b) Altered version of the observation view.

Figure 4.19: Images showing the difference between the original and altered versions of the high fidelity prototype's observation view.

# 5

## Results

From our observations it was clear that the LEGO ALMA installation did not have an intuitive user interface. A majority of users became confused when they first approached and it was difficult for them to understand where the interaction started. There was nothing that immediately encouraged users to explore the installation as there were no hints to help them. This resulted in the installation requiring a guide to stand beside it to assist users by providing a guided experience instead of one where the user explores and learns by themselves.

A large amount of (for non-expert users) complex or unnecessary information was presented to users on the screen, which only caused confusion instead of encouraging them to learn more. As users had to rely on a guide to provide explanations, the installation did not support learning through engaging tangible interaction and exploration.

The results from the low fidelity prototype showed that reducing complex visual information increased user curiosity. Furthermore, it was observed that users asked more questions about the ALMA radio telescope after testing the prototype and showed greater interest in the concept of interferometry. However, this may be a result of who the participants were in combination with them being provided additional information afterwards, which likely sparked further discussion.

Comparing the low fidelity prototype to the real installation, the physical buttons were placed much closer to the participant in the prototype, making them a lot easier to reach. Additionally, shifting attention between the screen and the board was easier in this prototype due to the elements being closer to each other than in the real installation. This made a notable difference in how quickly the participants noticed changes on the screen compared to later prototypes, making the prototype more engaging.

This prototype also provided a clear interaction flow, including a well-defined beginning and end. Users did not require additional guidance to understand how to interact with the system unlike the original design. The animation provided participants with clear instructions, guiding them through the interaction with minimal additional support. This also works to support previous research suggesting that animations can support learning, increase curiosity, and encourage engagement with scientific concepts Barak and Dori (2011).

The mid fidelity prototype produced results that both allowed the knowledge gained

from the low fidelity prototype to be further expanded upon, and new knowledge to be gained. For example, due to the success of the first animation, see figure 5.1a, more were added to support and guide users further during the interaction experience. As new functionality had been introduced, more complex concepts needed to be communicated, which made the way the animations were designed even more vital. This was shown to greater degree when comparing the first animation with the newer ones. The reset animation had to be revised once as it initially only showed three antennas being moved to the storage area, making some users believe only they only needed to move three antennas. The final version of this reset view showed three sets of three antennas being placed in the storage area, see figure 5.1b. Furthermore, the animation instructing users to spread or gather the antennas on the board was never truly perfected, as users continued to have difficulties understanding the animation throughout every test. However, the supporting text added for it in the high fidelity prototype helped significantly with this, see figure 5.2.



(a) High fidelity prototype's guide view



(b) High fidelity prototype's reset view

Figure 5.1: High fidelity prototype's guide and reset views

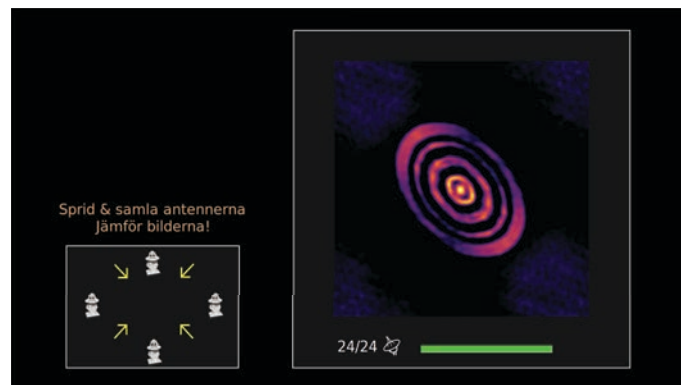


Figure 5.2: High fidelity prototype's observation view

The introduction of sound into the mid fidelity prototype was partially successful. Using sound it was possible to pull the users' attention towards the screen, if even momentarily, where they could see the results of placing antennas on the board. This shows how using sound appropriately can direct users' attention towards specific areas, allowing the designer to control what the user focuses on to some degree.

The high fidelity prototype was deemed an overall success. Users were able to follow the flow of the design well with minimal confusion regarding what they were

supposed to do. The confusion that existed with navigating from the video and selection views during the mid fidelity prototypes were gone with the high fidelity versions of them, see figure 5.3. The users generally felt satisfied after learning the idea behind ALMA and how the telescope works with interferometry. This is despite the fact that the concept was never explained to them, which aligned with the exhibition’s educational goals. Most users did not only enjoy using the installation, they wanted to use it.



(a) High fidelity prototype’s video view



(b) High fidelity prototype’s selection view

Figure 5.3: High fidelity prototype’s video and selection views

However, several limitations were also identified during the testing process. For example, due to the number of antennas and sensors matching exactly, there were very few possibilities for the users to experiment with antenna placement on the board. This greatly limited how well they could experience the different results produced when spreading and gathering antennas. Furthermore, this created a point where users did not know what to do, as there was nothing more to do except press buttons. This was solved by cutting the amount of antennas in half, making it impossible to cover every sensor at once. Consequently, this resulted in users being more engaged with the installation through this increased possibility to explore.

Another identified limitation was displaying a reference image of the object being observed. In the observation view, this image negatively affected the experience by reducing the users’ motivation to explore and experiment with the installation, even making some users feel that there was no point to do so. This was identified to stem from the fact that they already knew what the final image should look like.

A third major problem was that, even though sound feedback was used to confirm antenna placement on the sensors, users had the tendency to ignore the screen when first approaching the installation. Even after placing antennas and clearly and noticeably hearing the sound and looking towards the screen. This issue was prevalent in every design iteration and level of fidelity except the low fidelity prototype.

Even if a screen interface is designed perfectly, the physical elements of the installation must also be carefully designed and considered in order to create harmony and balance between the physical and digital components. The physical elements should not overpower or draw more attention than the screen interface. Both elements are equally important, and there should be a complementary relationship between them rather than competition for the users attention, since their combined role is to create an effective user experience that fulfills the intended purpose of the installation.

Finally, to summarize the results they have been condensed for an easier overview.

- The proximity of the tangible elements in a design and the area which output is shown plays a critical role in how intuitive, and consequently engaging, an installation is.
- Animation is a very powerful tool to guide users through interactions, though combining them with small amounts of text when attempting to convey more complex subjects may be necessary.
- Removing physical and digital elements from an interface can promote exploration and engagement in users if done correctly.
- Using audio is a great way to guide the users' attention toward specific areas or items that they are supposed to interact with in some way.
- Positioning the area where user receive output from a system within immediate line of sight of the input area reduces the risk of them tunnel visioning on one aspect of the installation.
- Ensure that the physical and digital components complement each other to improve the overall user experience.

# 6

## Discussion and Conclusion

To be able to answer the research question it is vital to go through the results, consider what they imply, and translate that into a concrete answer. A look at what was not done in this work is also important. This allows for clearer definitions of what future is needed, helping further show what limits the work has. Finally, the research question will be answered through a concrete list of key factors.

### 6.1 Discussion

The results show that there are several factors that should be considered when improving accessibility and engagement in tangible user interfaces aimed at science communication. However, to identify these key factors, one needs to go through the results in detail and figure out what part of the design had what impact on the user experience. As such, certain aspects of the results will be highlighted, and from them, key factors will be defined and discussed in order to show some of the benefits and problems that they inherently come with.

#### 6.1.1 Key factor 1: Reduce or prevent information overload

From the results of the prototyping process, particularly regarding how much information is given to the users at once, it is clear that removing unnecessary information from the installation's screen, reducing the risk of information overload, is important (Allen, 2004). This improves the installation's accessibility and supports learning for non-expert users. Because of this, information overload was deemed to be one of the key factors in improving accessibility and user engagement with installations at museums and visitor centers.

In the case of LEGO ALMA, the information provided to users was spaced out throughout the interaction process, subsequently preventing information overload, examples of which can be found in figures 5.2 and 5.3. This assisted users that lacked background knowledge to not only understand the installation, but also learn from it. Thus, the way one presents complex information should follow "*Immediate apprehendability on all scales*" as mentioned by Allen (2004). Both expert and non-expert users should be able to understand how to use the installation when they approach it, and when they do, understand what it is trying to teach them. If the installation fails at this there will be immediately noticeable consequences, both in

terms of the installation's accessibility and engagement, as well as how well it fulfills its educational goals.

However, it is also important to be careful with what information is removed. This is because removing too much might cause core concepts or necessary information to be lost to the users, but retaining too much complexity is likely to confuse and stress users leading to poorer memory performance (L. Li et al., 2020). In the case of LEGO ALMA and the prototypes developed for it this was relevant from the start. The installation's purpose is to communicate the concept of interferometry and how it is used in radio astronomy. However, this is challenging as interferometry is a highly complex subject that is hard to communicate effectively to non-expert users. As the goal of this project was to make LEGO ALMA as accessible and engaging as possible for a wide audience, a large amount of the information displayed in the original design was removed. This did allow for users to easily engage with the installation, proving how effective the reduction of available information was to increasing its accessibility. However, it was also clear that any details pertaining to more than the bare basics of interferometry was lost by doing this. Users were able to determine that the antennas were working together to produce an image, and that the image would change depending on how the antennas were positioned. However, any details regarding how the antennas worked together was entirely lost. It is important that the correctness of the information presented is not reduced for the sake of simplifying it. A science center's main purpose is presenting correct information to increase the available science capital, and thus it cannot distribute blatantly incorrect information. Thus, balancing how much information should be available, while not causing information overload in users, is an incredibly important factor in creating engaging and accessible installations, and thus one of the identified key factors.

If this was to be applied to installations in science centers at large it might allow for visitors to more easily engage with and learn scientific concepts. However, it could not be applied without careful consideration of the purposes of each individual installation as reducing the information presented for the purposes of simplicity could have severe consequences. Some installations will not suffer from information overload while others might have problems that limit their success in other ways. In these cases removing information would likely be largely harmful for their overall success and limit their potential. However, if individual installations were to be identified to have problems regarding user comprehension, then that may be a sign of potential information overload. In these cases a reduction in the quantity of presented information might help users take in and retain the knowledge presented.

### **6.1.2 Key factor 2: Balancing of resources**

The fact that users lacked any reason to explore the installation after placing all antennas on the board was identified as a limitation in the results. Furthermore, as mentioned in the results, this led to users becoming confused. Therefore, while the reduction of information overload allows for the implementation of more open-ended designs that are enticing for curious and exploration-driven visitors, as mentioned

by Gutwill (2008), one of the largest issues that hindered LEGO ALMA was the lack of motivation to explore. When users had placed all antennas on the board's sensors, there was nowhere else to move them, removing any reason to interact further with the board. As such, this limits the possibilities for exploration, resulting in unsatisfied and confused users, largely limiting the effectiveness of the installation. Therefore, in an attempt to encourage enjoyment and user participation, identified by Wideström (2020) as core elements of effective science center installations, and to generate a greater sense of exploration, the number of antennas was halved. This resulted in users being more prone to experiment, further increasing their engagement. This also resulted in new functionality for the installation. However, applying the same approach to other installations may produce different results.

This shows that it might be beneficial to limit the amount of resources available to users in an exploration and experimentation-driven installation in order to increase engagement. However, since a tangible user interface is reliant on physical components, it is important to be careful to not remove too much. This was never an issue for the LEGO ALMA prototypes as the reduced number of antennas only promoted further exploration. However, theoretically, if too many resources are removed it may severely limit an installation. For example, if too many antennas had been removed in LEGO ALMA, then users would not have been able to produce a satisfactory image. On the other hand, if too many antennas remained then the issue of users not being motivated to explore would remain. This suggests that limiting the options available to users promotes exploratory practices when interacting with tangible user interfaces. Though, to fully confirm this a more focused study would be needed on the subject.

Something else became noticeable after halving the amount of antennas in LEGO ALMA though. While removing the physical elements did help increase user engagement with the installation through exploration, they still required a motivation to start exploring. This suggests that, just because the possibility of exploration is present, users may need something to make them start the process of discovery in the first place. This could be a result of a flawed interface, an innate lack of curiosity in the user, or something else. However, restricting the resources intended to inspire exploration among users may require additional instruction. This raises the possibility that implementing this without careful consideration could result in the installation needing to be substantially changed for it to properly function.

Because of all of this, the act of balancing the amount available resources for users was identified as a key factor in increasing user engagement with tangible interfaces. However, the implementation of it is not recommended in most cases since it may not be to the benefit of most installations. Instead, before applying the method, one needs to carefully deliberate about both the goal of the installation and what the method would add to it. It is recommended to attempt this method if one wants to try to increase engagement with installations or experiences through exploration however. Though being careful when attempting the implementation is imperative as doing it incorrectly may risk causing more issues than it solves.

### 6.1.3 Key factor 3: Input and output positioning

By comparing how users used the low fidelity prototype with the mid and high fidelity prototypes, it was clear that the users had a hard time realizing what the results of placing antennas on the board were in the higher fidelity prototypes. One of the key observations we made was that, while participants in the tests for the low fidelity prototype were able to immediately see the results of their actions, the users of the mid and high fidelity prototypes could not. This created the, in hindsight quite obvious, realization that when designing any interface, it is important that users realize what the results of their actions are. Therefore, making a tangible interface that is accessible and make users more engaged is all well and good. However, if the user fails to realize what the system's response is when they interact with it, even the best interfaces may fail. This was another problem that LEGO ALMA faced, as there was no immediate feedback from the installation when an antenna was placed on the board. Instead, the user had to look away from the board and up at the screen to notice that something had happened.

This is an issue that comes up all the time when designing installations, an example of which can be seen in figure 4.5. Because of this there are many ways one can get around it. Quite obviously, one of the easiest ways to do so is to think about the issue ahead of time and design the entire installation with it in mind. One way to do this would be by placing the relevant elements of the installation within immediate line of sight and close proximity of one another. Doing this properly would allow users to actively see both where they give input to the system and the resulting output. However, not doing this risks confusing and frustrating the users, making them leave the installation entirely. A concrete example of this is how the point of input for LEGO ALMA is the board, while the output is shown on the screen, and the fact that it is impossible to see the screen when looking at the board. The elements feel separate through their visual distance from each other.

Because of the importance and large-scale impact this can have on an installation, it was concluded that the placement of the input and output points is a key factor to improving the accessibility and user engagement in installations.

### 6.1.4 Key factor 4: Appropriate audio implementation

Another aspect that the original LEGO ALMA design totally lacked was audio. Because of this, an attempt to solve the issue of users not looking at the screen due to its placement, was to add sound to the system when an antenna is placed on the board. This worked to an extent as it made users look at the screen and made them more engaged with the experience as a whole, however it did not keep their attention on the screen for a long time as the board was still more interesting to them. Therefore, this created the realization that audio can have a large impact on an interaction experience, however, it is not without its flaws. Because of this, it would be reasonable to say that adding audio to an installation that lacks it in order to draw the attention of users to certain areas is an effective way to increase accessibility and engagement as was proven through our prototypes.

However, the implementation of sound in our prototypes showed that it comes with its own set of problems. The sound needs to be appropriate in the context of both the installation and the exhibition as a whole, and choosing the right sound is difficult. Using the wrong sounds may disturb the users' engagement with the installation, even if they fulfill their intended purposes of increasing engagement. The volume of the sound needs to be properly adjusted so that it is loud enough to be clearly heard when using the installation, but low enough that it is not disturbing for other visitors not using it. And finally, the sound needs to come from the correct location, as a mispositioned speaker may draw users attention away from the installation as a whole.

All of this can be summarized into one key factor. The introduction, and appropriate use of, sound can increase both accessibility and user engagement.

### **6.1.5 Key factor 5: Combining animation and text**

One of the first problems faced in this work was how to give users clear and comprehensible instructions without excessive amounts of text. However, this was something that was solved very early on in the prototyping process through the combination of text and animations in the low fidelity prototype, see figure 4.10. As a previous study on how visitors use exhibit labels in art museums shows, visitors do read text (Reitstätter et al., 2022). Therefore, when reducing the amount of presented textual information, designers should not remove all text. The study suggests that while most visitors are unlikely to read long paragraphs, they instead prefer to read select parts or engage with visual and interactive elements of the exhibit. Furthermore, the study showed that the way texts are presented, their placement, and their visual clarity strongly influence whether visitors will read them or not. Because of this, one way to reduce potential information overload in an installation is to replace some written instructions with animations. This is further supported by our findings working with LEGO ALMA, showing that animations can successfully support user guidance and interaction by themselves. This is even further supported by a study by Baylor and Ryu (2003) that states that animation has been recommended in modern education as a way to improve interactivity, engagement, and learning.

One important advantage of animation and visual communication is that it allows information to be understood by users from different linguistic backgrounds. Language itself may limit the audience of an installation, as it mainly targets visitors who understand the language being used. Visual communication, on the other hand, can communicate ideas in a more universal and accessible way.

This can be seen in globally recognized media such as the animated series “Tom and Jerry” (2026), which is watched around the world despite containing very little dialogue. Its popularity largely comes from its reliance on visual storytelling, movement, and expression rather than language. A similar concept can also be seen in older “Mr. Bean” (2026) episodes, where audiences are able to understand and enjoy the story despite the minimal use of spoken language. If, like LEGO ALMA at OSO, an installation is designed with a Swedish speaking audience in mind, that

will undoubtedly exclude certain visitors that are unable to understand the Swedish language. Thus, the usage of different kinds of imagery like animations opens the doors to a wider audience without necessarily needing to translate most text into more languages. Because of this, it can be concluded that text should still be used in installations when necessary, particularly in situations where images and animations alone are not enough for communicating information effectively to a wider audience.

### **6.1.6 Key factor 6: Coherency between the physical and digital**

As mentioned in the results, each part of a design needs to complement the others. This comes from the realization that when one part of LEGO ALMA is vastly more accessible than the other, it becomes difficult for users to create a connection between the two. One thing that showed this clearly was how, even if the users of the installation were aware of the screen, they failed to understand the connection between it and the board. Usually, even completely ignoring it. Even though animations can improve accessibility and help communicate information without relying heavily on language, this does not necessarily mean that they are enough to pull users' attention toward elements in the installation. During the LEGO ALMA tests, the physical components of the installation often attracted more attention than the digital screen itself. Even when animated guidance and videos were displayed on the screen some users ignored them completely and focused only on interacting with the physical LEGO elements. Similarly, certain animations intended to encourage users to spread or gather the antennas did not always succeed in directing user behavior as intended. Showing that there was a level of disconnect between the digital and physical elements of the design that just improving the digital UI could not overcome.

This suggests that designing a visually accessible and user-friendly interface alone is not enough to guarantee successful engagement and learning in tangible science communication installations. In installations based on tangible interaction, both the physical and digital elements are equally important, and neither should be treated as secondary to the other. Instead, the relationship between physical interaction and digital feedback needs to be carefully designed so that both elements support one another rather than compete for the users attention. Therefore, learning experiences can become more engaging, intuitive, and understandable in educational environments and science centers (Pike et al., 2009). This is an important factor in improving engagement and accessibility in museums and science centers.

## **6.2 Future Work**

In regards to the LEGO ALMA installation in Onsala, it is still in need of improvements to enhance its usability. The physical elements of the installation, such as the buttons and the sensors, were shown to be placed in a way that was not fully comfortable for many users to use during testing. If a user were to stand in front of the screen, the distance between their hands and the buttons become too big,

especially for users with shorter arms which is the norm. This results in users constantly needing to move around the installation in order to press buttons and place antennas.

One way to possibly reduce this is to relocate the buttons to an area that is easier to reach. A possible solution to test would be to place the buttons flat on the board, which would make them both easier to reach as well as more obvious when the users first approach the installation (see D.7). Obviously, this idea has not been tested, and therefore it cannot be confirmed as an effective solution, but it is believed to be.

Another issue that was not fully solved during this project was the need for users to actively move their heads to look between the board and the screen. Testing indicated that this movement reduced both the users awareness of what was happening on the screen while they were interacting with the antennas, as well as their engagement with the installation as a whole. As a result, users pay less attention to what actually happens when repositioning the antennas, resulting in them missing critical information.

One possible way to improve this could be to position the screen lower and closer to the board in order to keep the screen more aligned with the users eyes when placing antennas. This would possibly allow users to shift their eyes rather than moving their entire heads whenever they want to look at the screen. However, this suggestion was obviously not tested during the project and is just an idea. Therefore, further testing and evaluation would be required to know whether this change can actually improve the accessibility and average user experience of the installation.

Our redesign of the LEGO ALMA installation was aimed at users without any prior knowledge of ALMA or interferometry. To do this a lot of complex information that was available in the original design was removed from the interface. To attempt to broaden the target audience and provide additional information for users who want to learn more about ALMA, an advanced mode could be introduced in the future. This advanced mode could serve as the next step after users have tested the default mode. The suggestion is that the user can switch between the default and advanced views depending on their background knowledge. This advanced view could attract more advanced users interested in space science to learn more about the ALMA radio telescope and interferometry. However, as with all other suggestions for future work, it would need to be tested in order to see how effective it is.

### **6.3 Conclusion**

Finally, to conclude this work and provide a concrete answer to the research question, this thesis identifies six key design factors that may improve accessibility, engagement, and learning in tangible user interfaces for science communication. These were extracted from the results through the discussion and contribute practical design principles for the development of accessible and engaging TUI installations in science center environments. The factors presented are particularly targeted at

younger audiences interacting with complex scientific concepts, such as radio interferometry, as that was the target audience of this work.

- Key factor 1: Reduce or prevent information overload
- Key factor 2: Balance available resources to promote exploration and engagement
- Key factor 3: Position input within the immediate line of sight of the output
- Key factor 4: Implement audio to increase user engagement
- Key factor 5: Combine animation with text to convey concepts or instructions
- Key factor 6: Design physical interaction and digital feedback so that both elements support and complement each other

Together, these factors provide practical insights into how tangible and digital interaction can be combined to support accessibility, engagement, exploration, and learning in interactive science installations. While every installation has different requirements and contexts, the findings of this work suggest that carefully balancing physical interaction, digital feedback, guidance, and exploration plays an important role in creating intuitive and engaging user experiences.

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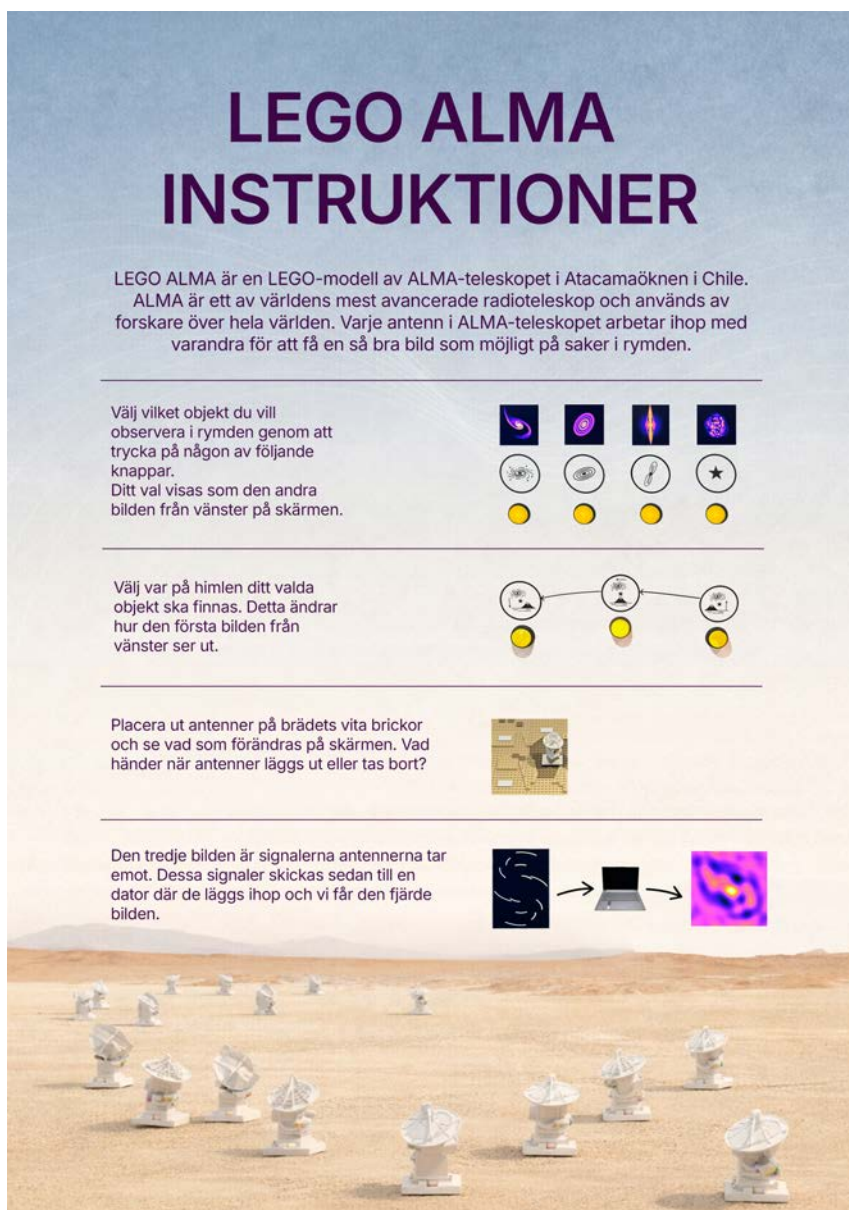
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# A

## LEGO ALMA Instructions

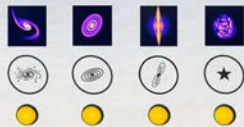


**LEGO ALMA  
INSTRUKTIONER**

LEGO ALMA är en LEGO-modell av ALMA-teleskopet i Atacamaöknen i Chile.  
ALMA är ett av världens mest avancerade radioteleskop och används av forskare över hela världen. Varje antenn i ALMA-teleskopet arbetar ihop med varandra för att få en så bra bild som möjligt på saker i rymden.


---

Välj vilket objekt du vill observera i rymden genom att trycka på någon av följande knappar.  
Ditt val visas som den andra bilden från vänster på skärmen.




---

Välj var på himlen ditt valda objekt ska finnas. Detta ändrar hur den första bilden från vänster ser ut.




---

Placera ut antenner på brädets vita brickor och se vad som förändras på skärmen. Vad händer när antenner läggs ut eller tas bort?



---

Den tredje bilden är signalerna antennerna tar emot. Dessa signaler skickas sedan till en dator där de läggs ihop och vi får den fjärde bilden.



The instruction sheet is set against a background image of the ALMA observatory in a desert landscape.

Figure A.1: Instruction sheet for the LEGO ALMA installation that was placed beside the screen to guide users step by step.



# B

## Initial Timeline

The project will start off with a few visits to the OSO during the first weeks to get a good idea of the issues surrounding the subject matter. These visit will include personal observations and experimentation with the installation, as well as observations of users interacting with the installation as well as some small tests.

These observations will then fuel the next phase of the project which is the start of preforming the first rapid prototyping. This will include ideation and sketching to come up with some initial designs, as well as performing some tests to see what design idea holds the most promise for future development. These tests would not be performed at OSO and instead they would be done on Chalmers campus to make it possible to perform more test than would be possible at OSO.

Mixed in with this early rapid prototyping the intention is to do a study visit to Universeum in Gothenburg. The purpose of this visit is to investigate how other educational installations have tackled the problem of how to convey a complex concept to an audience with little to no prior experience on the subject.

After the testing of the first prototypes is finished it will be followed by further iterations of the most successful prototype(s), creating one mid fidelity prototype that is then tested two or three times at OSO on the intended target audience. These tests are intended to be performed in the middle of March and the start of April. After the March test is finished the prototype will be iterated upon before the April tests to allow for some attempt to improve the design to allow for a faster development cycle.

After the tests of the middle fidelity prototypes a final, high fidelity prototype will be developed based on the feedback gotten from the previous tests. This one would be implemented by making major modifications in the software used in the installation before the project started. This design would then be tested at least once before the final version is created for a final evaluation.



# C

## Questions asked during the stakeholder interviews

## Interview Questions Template

This is a template of questions to be copied for each interview with stakeholders at OSO. It should contain general as well as project specific questions that we want answers to regarding the wants, needs, and preferences of each individual stakeholder at OSO.

### General Questions

#### Question 1:

##### Goal

What is the overarching goal of the OSO visitor center?

Answer:

- What do you want it to achieve?
  - Answer:

#### Question 2:

##### Emotional

What is the intended experience for visitors at the center?

Answer:

- Do you think it manages to provide this experience at the moment? Why, why not?
  - Answer:
- Is there anything missing for the visitor center to accomplish this?
  - Answer:

#### Question 3:

##### Learning

What three key things do you want visitors to take with them when they leave the center?

Answer:

- Should they have gained deep knowledge or just a surface level understanding?
  - Answer:

#### Example

Question Question Question Question Question Question

Answer: ...

Follow-up Questions (if you can think of any)

- Question
  - Answer:

Figure C.1: First page of the questions asked to the stakeholders during the stakeholder interviews.

## Project Specific Questions

### Question 1:

#### Goal

What is the purpose of the exhibit?

Answer:

### Question 2:

#### Problems

What user groups does the prototype work and not work for?

Answer:

Follow-up Questions (if you can think of any)

- Why does it work for the groups it works for?
  - Answer:
- Why doesn't it work for the groups it doesn't work for?
  - Answer:

### Question 3:

#### Learning

What do you want the visitors to gain from the exhibit?

Answer:

### Question 4:

#### Learning

Do you think the prototype helps you understand how radio telescopes work if you did not have any prior knowledge about the subject?

Answer:

- Does the LEGO ALMA prototype miss any important functions related to the antennas that it would need?
  - Answer:
- Is it even important that the prototype teaches the user how radio telescopes work in detail?
  - Answer:

### Question 5:

#### Problems

Which unit/s or parts are the most difficult to understand among the images on the exhibit's screen?

Answer:

- Why do you think that/those are the most difficult?
  - Answer:
- Is there any other part of the exhibit that you think might be particularly difficult to understand for first time visitors?
  - Answer:

Figure C.2: Second page of the questions asked to the stakeholders during the stakeholder interviews.

## C. Questions asked during the stakeholder interviews

---

### **Question 6:**

#### **Problems**

What do you think are the three biggest things that the LEGO ALMA is missing for it to reach its maximum potential?

Answer:

- Why did you choose those three?
  - Answer:

### **Question 7:**

#### **Inspiration**

If you have a chance to re-design the prototype, what will you do in general?

Answer:

- Could you motivate your answer for why you would do that?
  - Answer:

### **Example**

Question Question Question Question Question Question

Answer:

Follow-up Questions (if you can think of any)

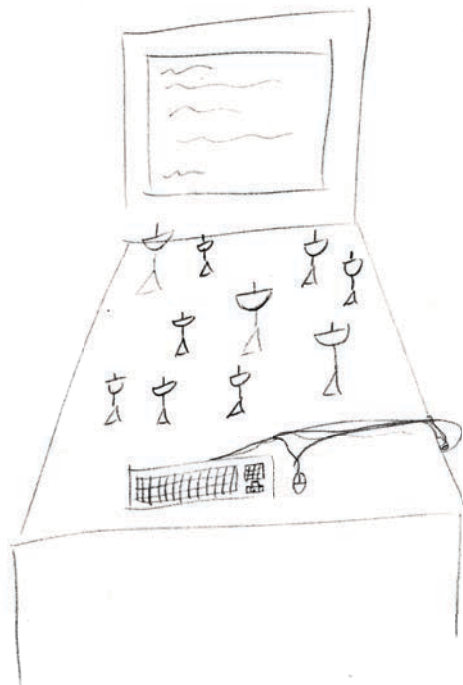
- Question
  - Answer:

Figure C.3: Third page of the questions asked to the stakeholders during the stakeholder interviews.

# D

## Ideation

Visitor-programmable exhibit.



- Visitors can "re-program" what the telescope sees/looks at.
- The antennas are pre-placed.

- Very high barrier for entry
- not accessible

+ Gives a closer.

Figure D.1: Image of sketch 1.

D. Ideation

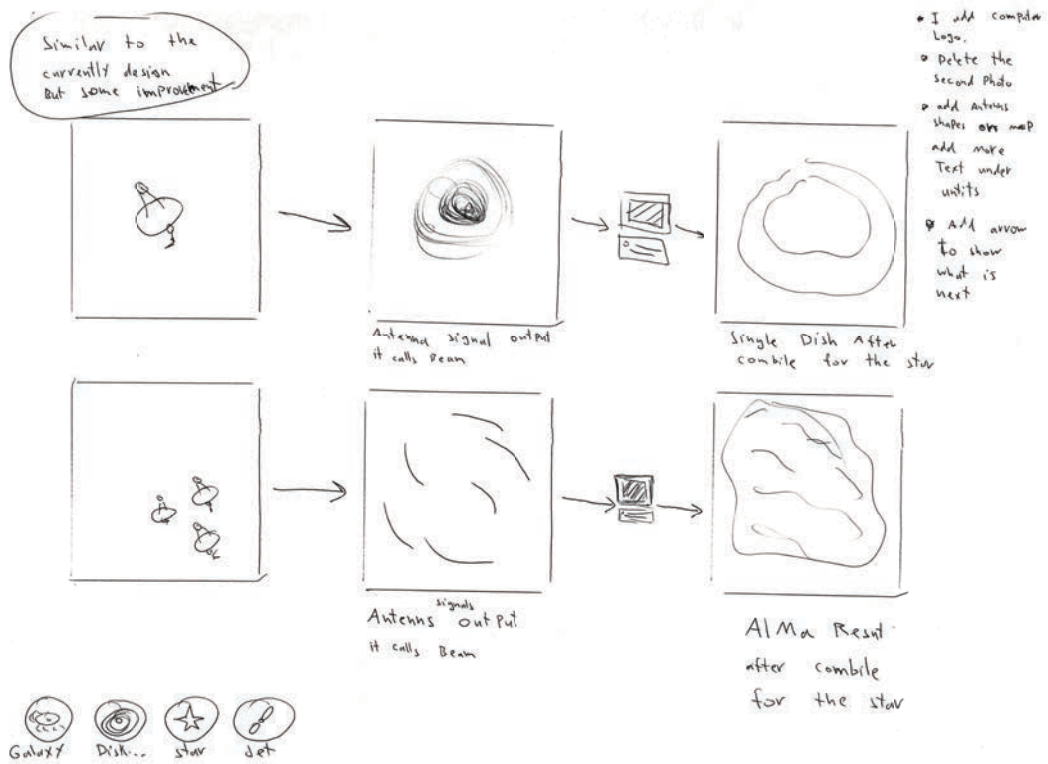


Figure D.2: Image of sketch 2.

Preplaced antennas → Make their properties affect the picture instead.

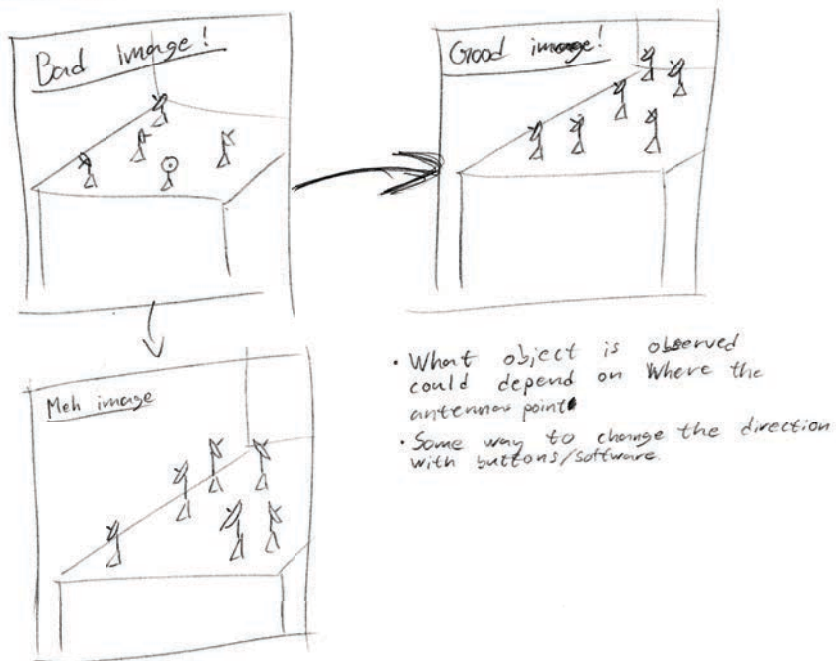


Figure D.3: Image of sketch 3.

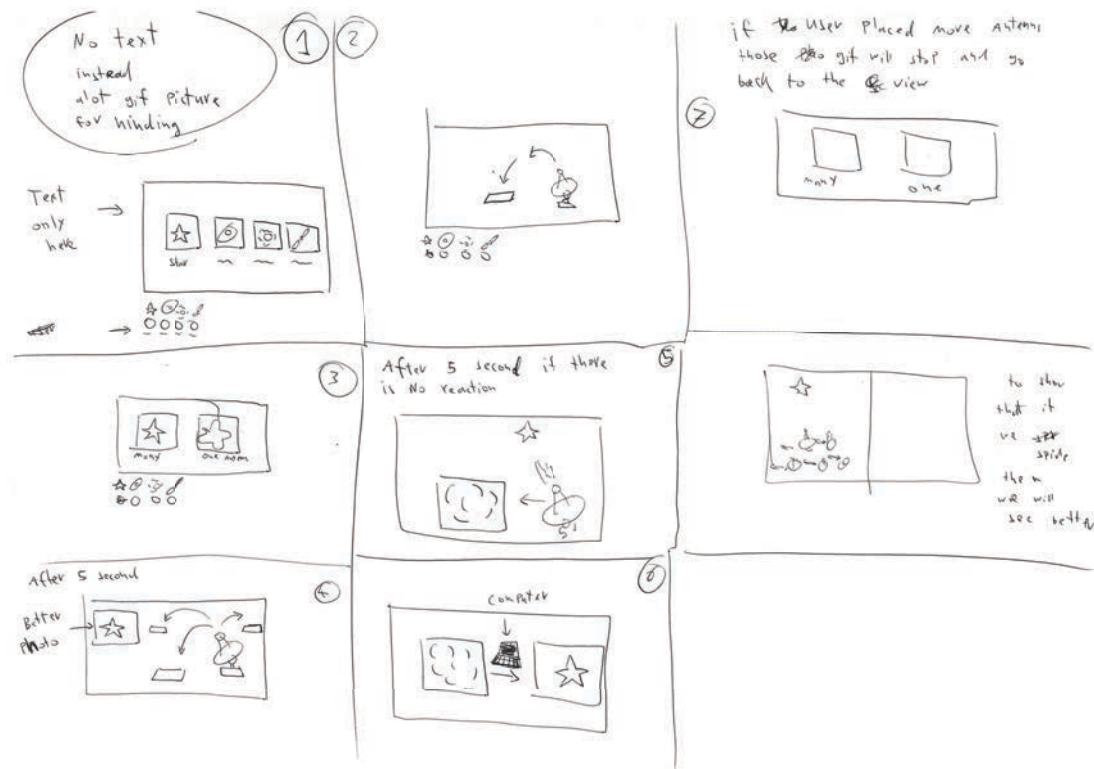


Figure D.4: Image of sketch 4.

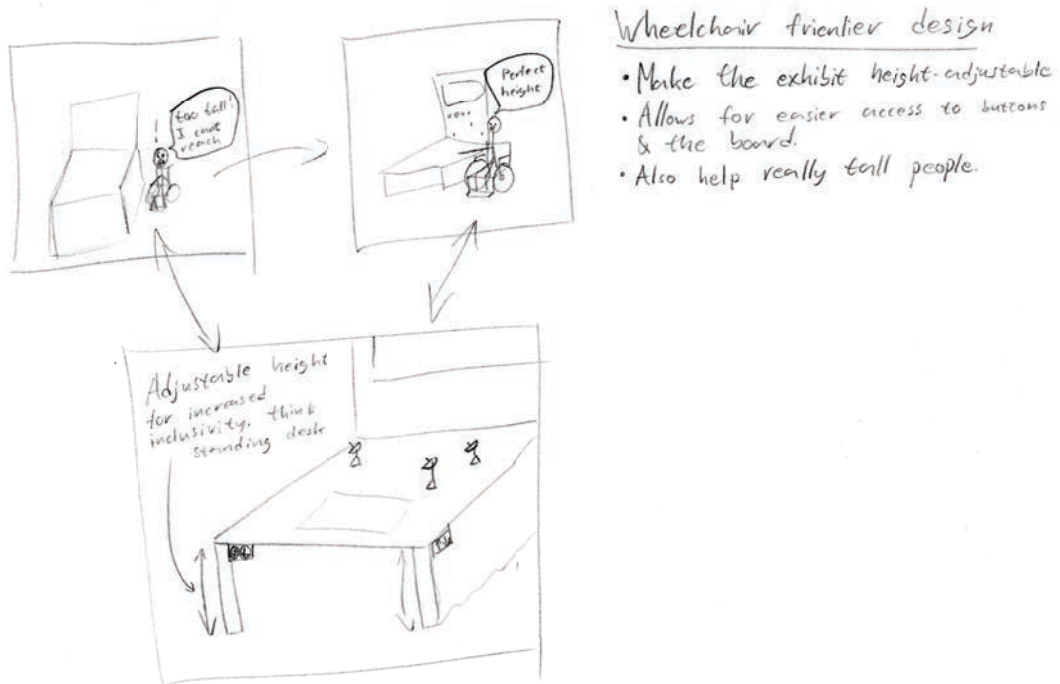


Figure D.5: Image of sketch 5.

D. Ideation

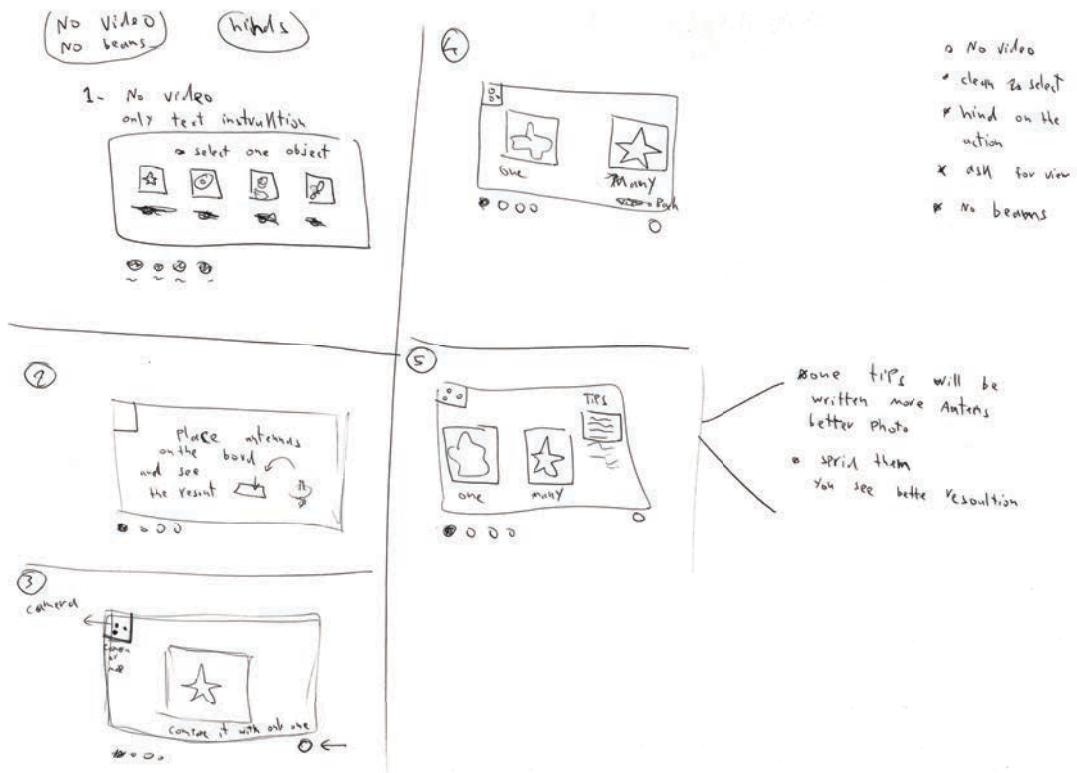


Figure D.6: Image of sketch 6.

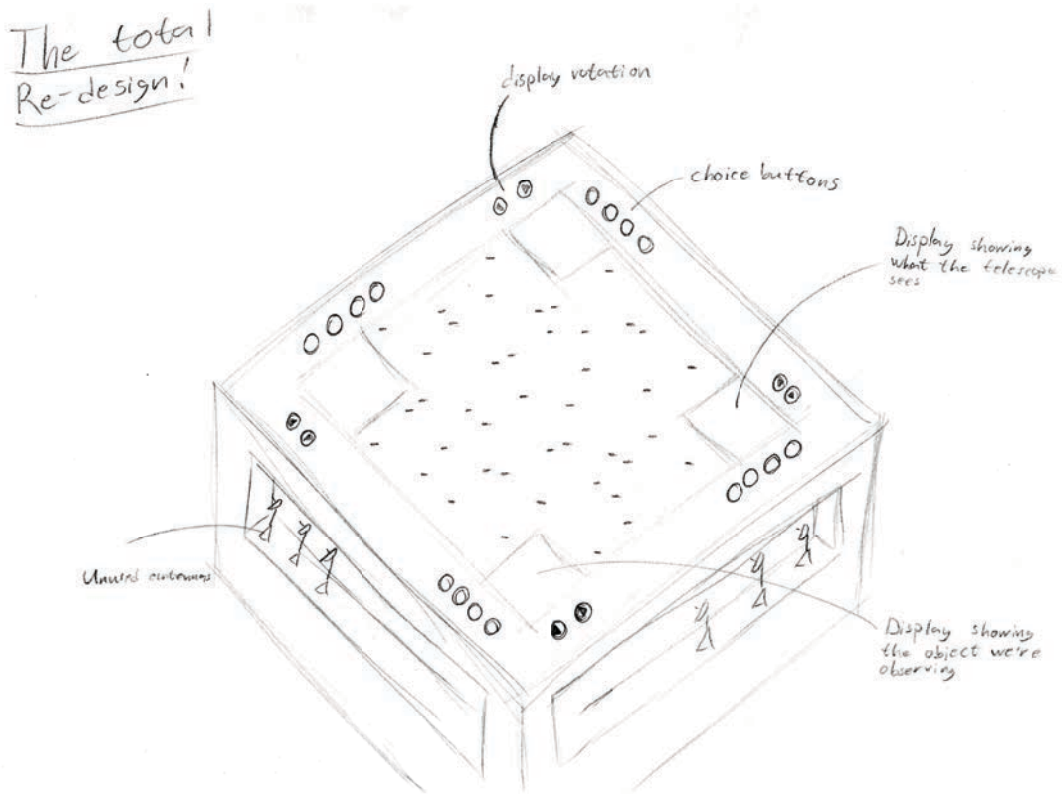
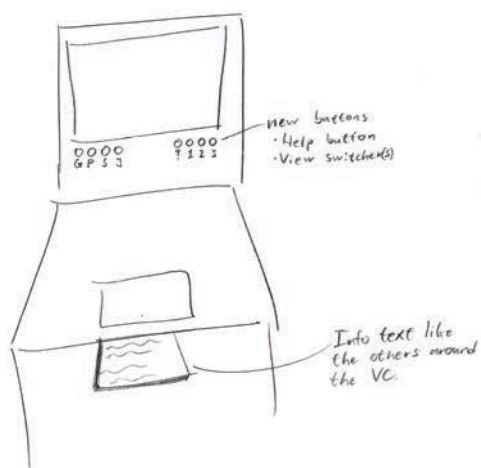


Figure D.7: Image of sketch 7.



Figure D.8: Image of sketch 8.



- Would require a new frame around the screen
- + would allow us to reduce confusion in visitors due to leftovers from older versions.
- People will, most likely not read the info text in most cases
- + Gives us the designers more room for experimentation.

Figure D.9: Image of sketch 9.

D. Ideation

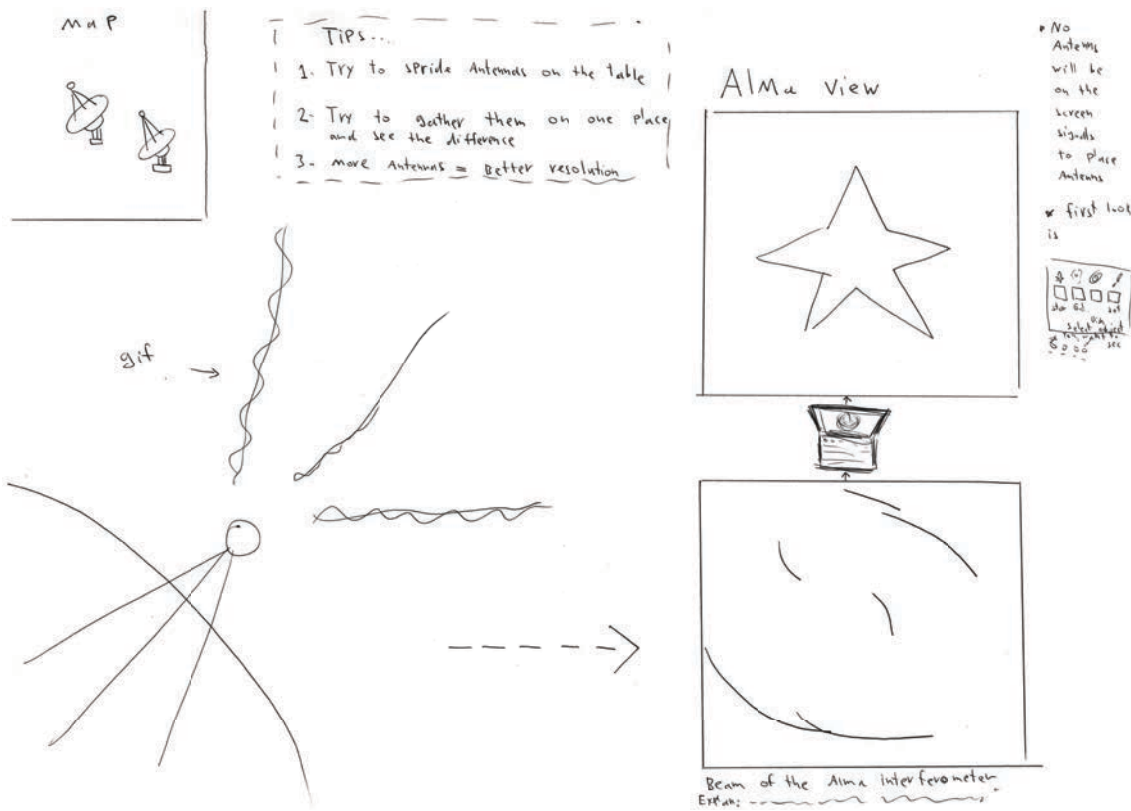


Figure D.10: Image of sketch 10.

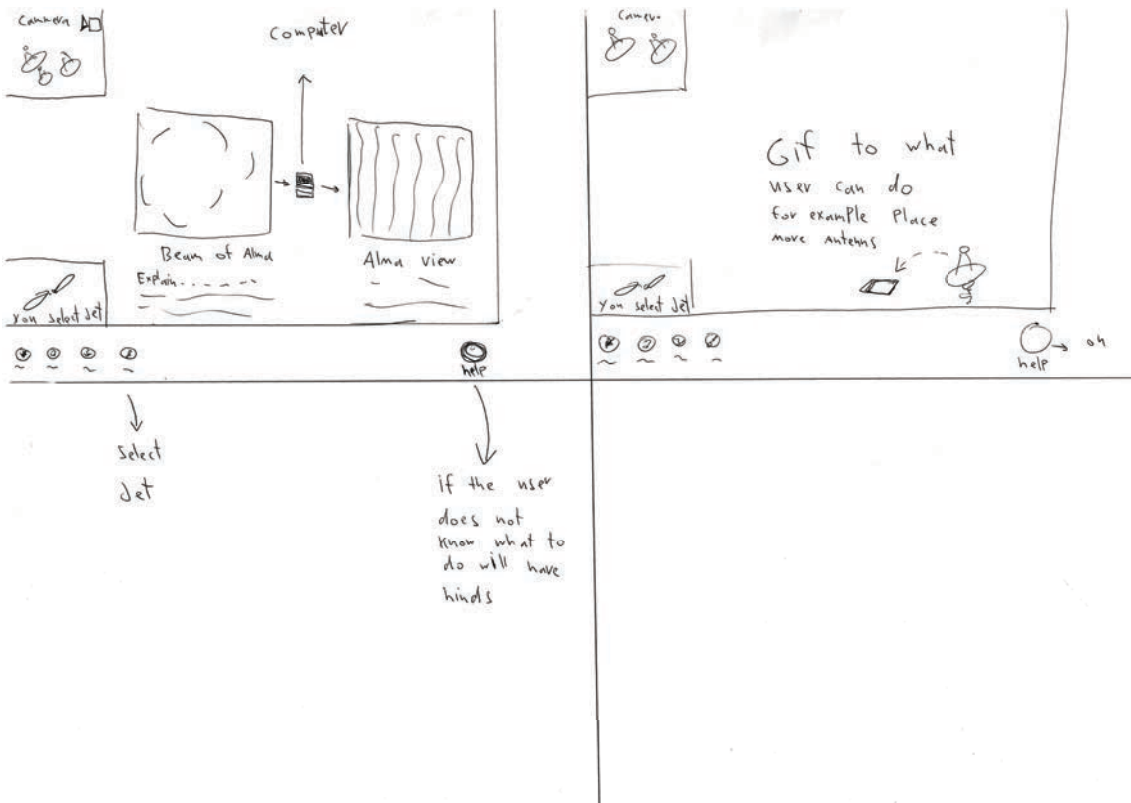


Figure D.11: Image of sketch 11.

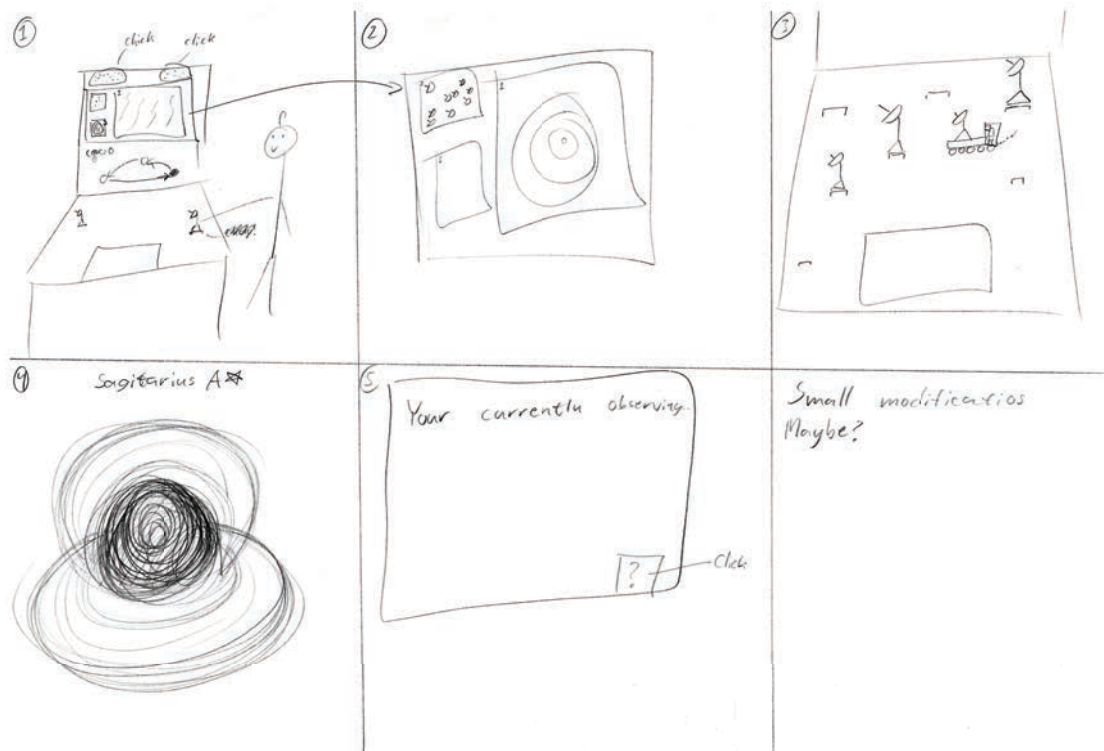


Figure D.12: Image of sketch 12.

Mindmap

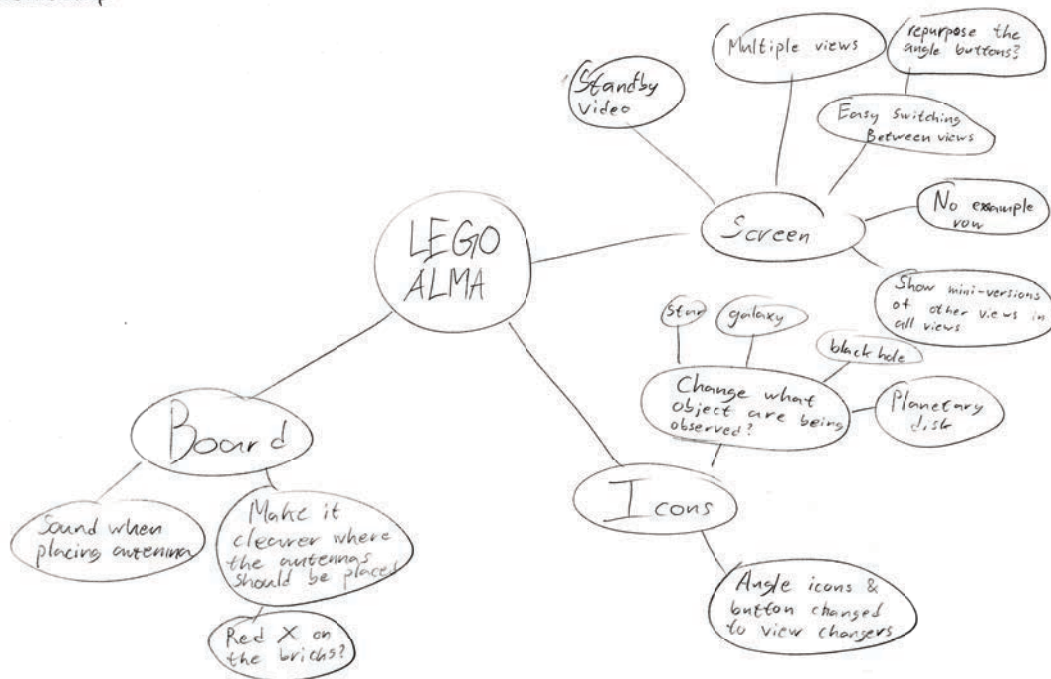


Figure D.13: Image of sketch 13.

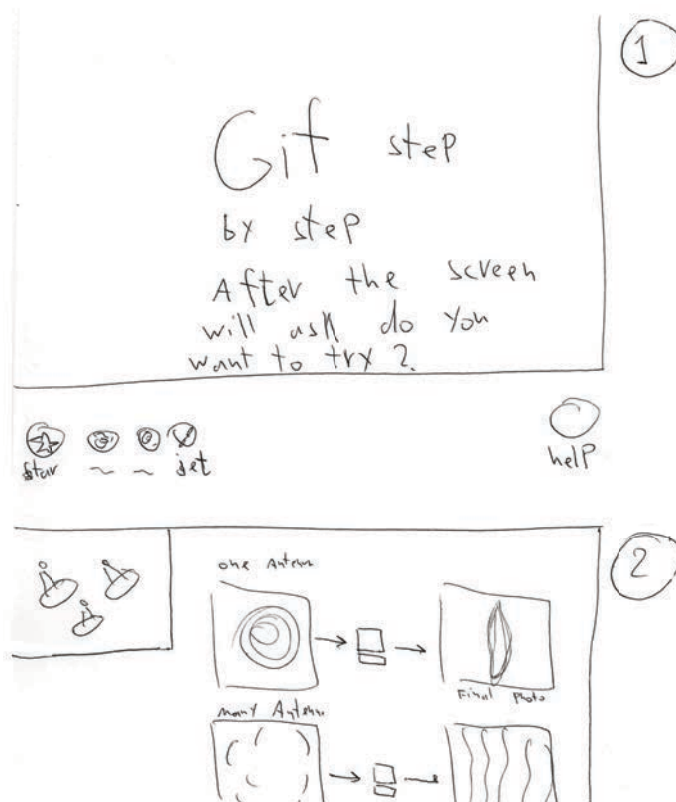


Figure D.14: Image of sketch 14.

# E

## Low fidelity prototype testing

### LEGO ALMA low fidelity prototype testing

We are in the process of redesigning the user experience of the LEGO ALMA installation at the Onsala Space Observatory. This redesign is intended to cover accessibility, intuitiveness, and how well it teaches the users about both how the ALMA telescope and radiotelescopes in general function.

In this particular test you will be interacting with a first low fidelity prototype of our redesign whose current focus is to minimize information overload. You will be given minimal guidance while interacting with the prototype, however, you are free to ask for help if you get stuck at any point. When you feel like you're finished using the prototype or after 10 minutes an informal interview will be held. During this you will be asked a few questions regarding your experience using the prototype. After this the session is finished and you are free to leave.

Note that we wish to record audio of the test and interview for documentation purposes and to make sure that nothing is missed. If you do not want to be recorded in any way make sure to tell us so.

This study is conducted in accordance with the ethical guidelines of Chalmers University of Technology and the European Union. You may withdraw from the study at any point: if you no longer wish to take part in the experiment, any data collected up to that point will be removed from the study and deleted. All data collected will be entirely confidential and any data referenced in the resulting report will only be done so by participant number. If you would like further information, please contact one of the researchers ([adamwi@chalmers.se](mailto:adamwi@chalmers.se), [alfutih@chalmers.se](mailto:alfutih@chalmers.se)).

**If you are willing to take part in the experiment, please print and sign your name and give the date below (participant's copy).**

Name:.....	Date:.....
Signature:.....	

**If you are willing to take part in the experiment, please print and sign your name and give the date below (researcher's copy).**

Name:.....	Date:.....
Signature:.....	

Figure E.1: Consent form provided to participants testing the low fidelity prototype.

### Masters Thesis - LEGO ALMA - low fidelity prototype testing

First - Qualitative User Test

**Take 10 minutes to explore and test the prototype.**

- Which part of the design was hardest to understand or use? Why?
  - Answer:
- What do you think the arrows that point towards the antenna mean?
  - Answer:
- What do you think the purpose of the arrow pointing away from the antenna is?
  - Answer:
- What did the prototype teach you about radiotelescopes?
  - Answer:
- What did the prototype teach you about what an antenna in a radio telescope does?
  - Answer:
- How easy was it to understand where the antennas should be placed?
  - Answer:
- Did you feel like you should look at the screen after you had placed an antenna for any reason and did you notice any changes on the screen? Why or why not, and what change did you see, if any?
  - Answer:
- Did you feel anything after having placed the first antenna? Did it make you want to place more antennas? Why or why not?
  - Answer:
- What do you think the large square area on the screen is showing you? Why?
  - Answer:
- What do you think the area in the top right of the screen is showing you? What do the icons represent?
  - Answer:
- What do you think the image in the top left corner of the screen is telling you?
  - Answer:

Figure E.2: Set of questions for testing low fidelity prototype.

# F

## Mid fidelity prototype



Figure F.1: Screenshot of the mid fidelity prototype's video view.



Figure F.2: Screenshot of the mid fidelity prototype's selection view.



Figure F.3: Screenshot of the mid fidelity prototype's guide view.



Figure F.4: Screenshot of the mid fidelity prototype's observation view.



Figure F.5: Screenshot of the mid fidelity prototype's reset view.