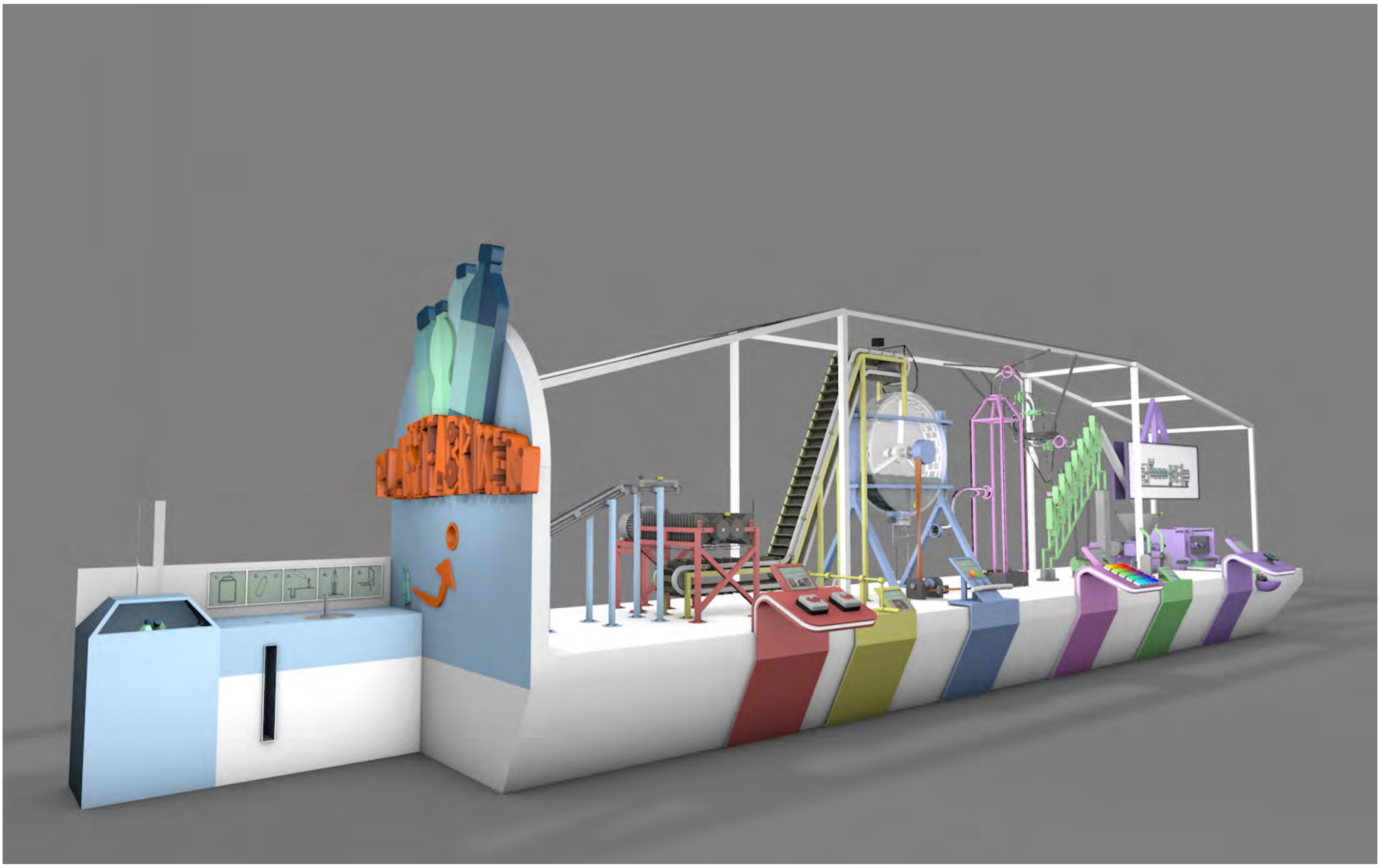

VALUABLE WASTE

Designing an interactive science centre exhibition about the plastic recycling process

Master of Science Thesis in Industrial Design Engineering

JONATAN GOTTFRIDSSON
LINUS TJÖRNEVIK

CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg Sweden, 2019

Department of Industrial and Materials Science
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Supervisor: Helena Strömberg
Examiner: Helena strömberg

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Master of science thesis

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ABSTRACT

Plastic pollution has become an increasingly considerable problem that affects both humans, animals and nature across the globe. One way to address this problem is to change peoples' view of the value of plastic. That would in turn induce a change in the approach to plastic to be more sustainable since it would be considered more valuable. A change in approach would also cause the behavioural change that is needed to reduce the plastic pollution. Changing peoples' view of something can and should be done in many ways. One way to do so is to develop a science centre exhibit that will trigger emotions, spread knowledge and enlighten people about the value of plastic which will function as a spark for the needed behavioural change.

This master thesis, called the Valuable Waste project, was about that science center exhibit. It was carried out by the Industrial Design Engineering master programme students Linus Tjörnevik and Jonatan Gottfridsson at the Department of Industrial and Materials Science at Chalmers University of Technology. The design bureau Boid was the project initiator.

The aim of the Valuable Waste project was to develop an interactive plastic recycling exhibit. The project was carried out in three phases. Phase one consisted of literature studies, observations and interviews. This phase also contained the development of the Exhibit Scoring method, with which structured and evaluating observations were conducted in order to define the characteristics of successful science centre exhibits. The result from this phase was the Successful Exhibit Guidelines list. The gathered data from phase one served as the foundation of phase two, where the concept library was formed and filled with numerous element concepts. The concepts were evaluated and morphologically put together to a first holistic concept, Plastfabriken 1.0. In phase three Plastfabriken 1.0 was further developed and redesigned in order to make it more realizable. In this phase, user tests were conducted. Phase three resulted in a second and final concept of the exhibit; Plastfabriken 2.0.

Plastfabriken 2.0 is a real working PET recycling machine that is developed to be the centerpiece of an exhibition at the science centre Universeum. It consists of the necessary elements needed for a plastic recycling process; *cleaning, shredding, washing, drying and creating,* and does thus have the function to recycle used PET into new molded plastic parts. Each element is designed to, according to the Successful Exhibit Guidelines, have an intriguing and enjoyable user interaction.

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During the course of this project we have had the privilege to interview the talented exhibit designers; Per Mauritzson, Ola Schönbeck, Håkan Sigurdsson and Anja Derwanz who all offered memorable and interesting meetings and we would like to thank all of you for taking your time to meet us. We would also like to thank Ramiro Fuentes, manager for sustainable business at Universeum, and Linea Kjellsdotter, researcher at Swedish National Road and Transport Research Institute, for the collaboration in this project.

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1. Introduction

This chapter introduces the master thesis project. It describes the background, project description and aim of the project but also the project's objective and research questions.

1.1 Background

In the year of 1907 the first ever fully synthetic plastic was invented. The discovery would later prove to play a crucial role in the upcoming hundred years of societal development. The material was known as Bakelite and marketed as "the material of a thousand uses ("Bakelite" 2015). With properties such as great insulation capabilities, high durability and heat resistance as well as ideally suited to mechanical mass production, Bakelite quickly became a worldwide sensation ("The history and future of plastics" n.d).

As the manufacture of plastics continued to improve and further develop, many new kinds of synthetic polymers were realised and produced over the years. The growing desire for specific material properties pushed the market towards where we are today. Development has reached a point where the properties of the material are so versatile that it can be found in almost any production, in all corners of the world ("Plastics, 100 years of innovation" n.d). Even in places where it should not be.

Figure 1. Plastic bottles littering our nature. Reprinted with permission.

Over the last 65 years production of plastics has increased more than 200-fold. From 1,5 million tons produced in 1950 to 381 million tons produced in 2015. To put these numbers into context, that equals a mass of 20% more plastic than the mass of the entire world's population together, annually (Ritchie and Roser, 2018). According to Ritchie and Roser (2018), in the year 2015 only 19,5% of all produced plastic was recycled whilst the same year 25,5% was incinerated. That leaves 55% of plastic waste disposed of as either landfill or discarded by littering or lost to the natural environment (see Figure 2).

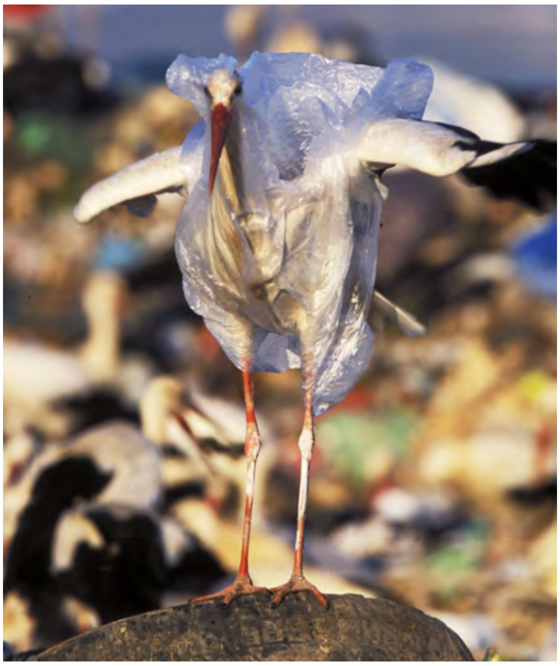


Figure 2. A stork entangled in a plastic bag. Reprinted with permission.

As a result, approximately 8 million pieces of plastic enters our world's oceans each day, killing over 100,000 marine animals annually. ("Plastic pollution - facts and figures" n.d). The pollution is directly related to our consumption - less consumption would result in less pollution. In Sweden we consume around 100 kg of plastics/capita and year. If all people would consume plastic at the same level as Swedes do, about 1000 millions of tons would be needed. Three times as much as the already unsustainable reality (Palm & Svensson Myrin, 2018).

With this prevailing status and situation, on everybody's mind should be the goal of improving the world's approach to plastic, both in regards to consumption and production but also disposal. To change people's approach, environmental consciousness needs to increase and our careless addiction to the convenience of plastic needs to be adjusted. Furthermore, in order to defeat plastic pollution, we need to completely rethink our approach to using, producing and designing plastic products ("World Environment Day 2018," 2018). Educating people about the environmental issues that the lack of adequate management of plastic waste and unsustainable consumption creates, is not enough to induce a behavioural change towards a more sustainable living in regards to plastics (Dahl, 2009). For behavioural change to happen it takes a substantial commitment of time, effort and emotion (Cherry, 2019).

Three factors to the problem are the lack of awareness, care and public engagement in plastic management and consumption (Allen, 2016). One way to address all these factors could be to change the view of the value of plastic. Plastic is, in most places in the world, seen as completely worthless once it no longer serves its purpose and is then carelessly thrown away. If the view of plastic would change to be seen as a valuable material that should be treated with respect and managed correctly, many of our problems occurring due to plastic pollution would be resolved. Changing the view of the plastic's value will change the approach to plastic to be more sustainable, which in turn creates a behavioural change. (Cherry, 2019).

With this as the core and fundamental mindset, in the autumn of 2018 a project was initiated to address the problem of peoples' view of the value of plastic. The project had the idea of using a science centre exhibition as the mediating tool that would spread knowledge, educate and emotionally influence users about plastic pollution and let them see and experience the effects of it. Science centre exhibitions often have the effect of triggering emotions and reflections needed for a behavioural change to happen (Davidsson, 2012) and does thus prove to be a suitable tool to use.

1.2 Project description

The initiative of the exhibition came from Boid, a product design studio situated in Gothenburg, Sweden. They, together with their parent company, Chalmers industriteknik and Universeum, Gothenburg's largest science centre, were the main stakeholders in the project. To find investors to fund the project, a decision was made to apply for the *challenge driven innovation* program at Sweden's innovation agency, Vinnova. To meet the requirements for applying to this program, the project had to have a wider spectrum of impact and thus consists of more than just an idea of a science centre exhibition. Added was a concept for a plastic educational model for primary school pupils and a digital knowledge portal about plastics. The application, now made up of three distinct products; an exhibition about plastics, a plastic educational model and a digital knowledge portal, was called "*Change behavior through innovative education model*". The aim of the model was to increase society's knowledge about plastics and its impact on the environment and create a societal behavioural change towards a more sustainable lifestyle.

This thesis project, also called the Valuable Waste project is a sub-project to the *Change behavior through innovative education model* project. The main task for the Valuable Waste project is to design an interactive plastic recycling machine that will act as the centrepiece at the exhibition about plastics, hosted at Universeum. This machine is referred to as an exhibit that is a part of the full exhibition. Hence, the Valuable Waste project is part of only the first of the three products of the *Change behavior through innovative education model* project - the plastic exhibition.

1.2.1. Main target group

In an interview with Universeum's scientific director together with their manager for sustainability, the information was communicated that Universeum's main target group is children in fifth grade. In Swedish elementary school this refers to children in the age of 11. However, Universeum's marketing is heavily family oriented which means that the activities, exhibits and information, should be taking into consideration that people in ages both younger and older than 11 should also be able to consume the available material. According to the interviewees this is partly one of the reasons why their main target is 11 year olds, because "since 11 year olds are an "in-between" age, designing for them makes the material suitable for both an older and younger audience as well". Since the exhibit is thought to be displayed at Universeum its target group will hence also be children in the age of 11.

1.3 Aim

In order to try and change people's view of the value of plastic - the aim of the Valuable Waste Project is to develop an interactive plastic recycling machine that will show people how valuable plastic can be.

1.4 Objectives

The first step in reaching the aim of the project is to gain understanding for how the industrial plastic recycling process works. With the gained knowledge, the process can be scaled down to be suitable for a science centre exhibit. Secondly, to study science centres and their visitors because science centres is the context wherein the exhibit should be placed in and the visitors because this is the main target group. Thirdly, to take the gathered knowledge and through a user centred design process, develop an interactive plastic recycling exhibit suitable for Universeum. The last objective is to provide guidelines for what an exhibit could contain and how it should be designed in order to be considered successful.

The development of the exhibit will be taken as far as to a design proposal and delivered as a 3D-model along with the guidelines. The results aim to assist the further development and realisation of the exhibit.

'Exhibit' refers to an independent part of a complete exhibition. For example; an exhibit that, by means of tubes and pumps, shows the body's blood system situated in the section of the science centre that holds the exhibition "Our Bodies".

1.5 Research questions

The study will strive towards achieving the aim by answering the following three research questions.

a. How can a science centre exhibit be designed to get the users to reevaluate their view of the value of plastic?
b. How can a science centre exhibit be designed to be able to execute a functional plastic recycling process and create new parts?
c. How can an exhibit be designed to ensure it is suitable for a science centre?

1.6 Reading guide

Chapter two contributes to a brief understanding of the plastic recycling process that is needed to follow the rest of the report. It also examines how existing plastic recycling initiatives utilize a simplified process compared to the industrial process.

Chapter three describes the design process and methods that have been used in this project.The third chapter is divided in three phases which corresponds to the phases in the project.

Chapter four provides the results from phase one in the project. It also contains an analysis of these results and the development of guidelines.

Chapter five focuses on the result from phase two in the project which contains idea generation and concept development. A first holistic concept is presented.

In the sixth chapter, the results from phase three are delivered. The chapter provides an analysis of the user tests, further development (realization) of the concept from the previous chapter, as well as the final concept.

Chapter seven discusses whether the research questions have been answered. Further it discusses the use of methods and provides suggestions for further work.

Chapter eight concludes the project's findings and summarizes the insight

2. The plastic recycling process

The following section contributes to the understanding of plastics and the plastic recycling process. The process exists in various levels of complexity and thoroughness, ranging from full-scaled automated industrial processes to small-scaled versions with simple tools. In the complex end, the bottle-to-bottle recycling process that is conducted by Veolia PET Svenska AB (URRC Process, n.d) can be found. They use the United Resource Recovery Corporation (URRC) process called UnPet (Transforming, n.d) in order to produce safe-to-use beverage bottles. The other end of the spectrum contains do-it-yourself projects as Precious Plastic (Hakkens, 2016), which is described below.

2.1 Plastics today

Plastics is a broad term including a wide range of materials that are malleable organic compounds. The properties vary between the different plastic materials and depending on the application, the plastic material can be given certain properties by adding chemical additives to the material ("Plastics additives" n.d). One way to classify plastic is whether it is a thermoplastic or thermoset ("Plastic: composition and types of plastics" 2012). The main characteristics for a thermoplastic is that it can be melted without changes in its molecular structure, reshaped and molded repeatedly. A thermoset, on the other hand, undergoes an irreversible chemical reaction when it solidifies. Upon heating, the thermoset does not melt but decomposes and cannot be reshaped. As this thesis is about the plastic recycling process, the word plastic refers to thermoplastics in this report.

2.2 Recyclable plastics

The recyclable plastics can be found within the thermoplastic group of plastics. About 80% of all plastic items we are surrounded by are made of thermoplastics (Hakkens, 2016).

2.2.1 Resin Identification Code (RIC)

In order to facilitate for manufacturers to properly label their thermoplastic product, common plastics have been given a specific identification number. The number is called a Resin Identification Code (RIC) and is given by American Society for Testing and Materials (ASTM International) (ASTM D7611/D7611M - 18). The list of recyclable plastics range from one to seven:

1. PET (Polyethylene terephthalate)
2. HDPE (High-density polyethylene)
3. PVC (Polyvinyl chloride)
4. LDPE (Low-density polyethylene)
5. PP (Polypropylene)
6. PS (Polystyrene)
7. Other plastics that does not fit in one to six

The RIC is known for being contained in a triangle made up of arrows and has often been interpreted as synonymous to recyclable (see Figure 3). However, in the latest version, the number is now contained in an enclosed triangle (see Figure 3). ASTM International stresses that the RIC is not recyclable code and a product marked with a code is not by definition recyclable (ASTM D7611/D7611M - 18). The RIC is in this thesis used to identify plastics and to make it more specific. When using the word plastic in this report, it refers to the plastics labeled with RIC 1-6.

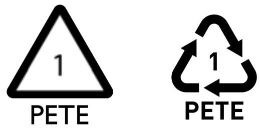


Figure 3. The new RIC symbol for PET to the left and the old to the right.

2.3 Industrial plastic recycling process

The plastic recycling process is a process where plastic waste is recycled to be used in new products. The process can differ somewhat depending on what type of plastic is recycled and for what application it is recycled. However, general steps that apply to most of the recycling processes are: *collecting, sorting, shredding, washing, drying, pelletizing* and *manufacturing/creating* (see Figure 4).

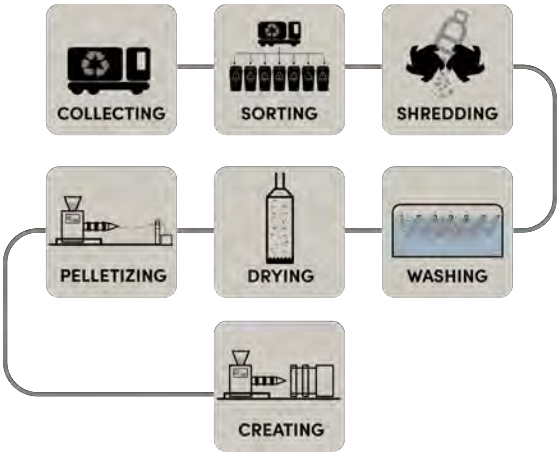


Figure 4. An example of what the plastic recycling process can look like. The steps, especially the sorting step, can occur in other orders or multiple times. Thus, this figure does not represent all plastic recycling processes. Author's own copyright.

Collecting

This step can be performed differently depending on where the plastic is collected. This is due to the fact that the collection of plastics can be managed either by the state, private companies or there is no system for it. In Sweden, for example, it is regulated by law that a professional beverage supplier must be connected to an approved return system (SFS 2005:220). One example of a well established system for collecting PET bottles in Sweden is Pantamera ("Vårt uppdrag" n.d). The main goal of this first step is to gather all used plastic to be able to process and recycle it.

Sorting

The purpose of this step is to make sure that the quality of the recycled plastic will be as high as possible and that the new part being created can be recycled again. The sorting step can be carried out both before and after the shredding of the plastic. If it is done before, it is common that the plastic is sorted manually. If it is done after the shredding, the granules can be sorted by automated NIR (Near Infrared) technique. This technique utilizes the fact that different plastics reflect different wavelengths when exposed to wavelengths near the infrared spectra. The sorting machine will then sort the different plastics by blowing a precise stream of high velocity air onto plastic granules of the same type - separating them from the rest. Another common technique is the sink-float separation method that utilizes different floating properties. PET, for example, sinks when put in water, while PVC floats (Pandey, Ruj and Srivastava, 2015) .

Shredding

In this step, the plastic waste is reduced in size and made into granules. This is usually done by letting the plastic parts enter a grinder where sharp blades are rotating against each other. When the plastic is caught by the blades in the grinder, their rotation and tightly placed blades will tear the plastic into smaller pieces. This is done in order to make the material ready for further treatment in the process.

Washing

Like in the sorting step, the purpose for this step is to reduce the amount of impurities and residues among and attached to the granules. It is desirable to eliminate as many impurities, residues, adhesives and other contaminants as possible. This can be done by for example water baths, friction washers, or a washing line where the granules are thrown and swirled around in the water. Detergents and disinfectants are often used to assure a high level of cleaning ("The plastic recycling process", n.d).

Drying

After the granules have been cleaned, it must be dried. Different types of drying methods are used, depending on the level of dryness that is desired for the particular application. For PET, the moisture level must be less than 1% to avoid the appearance of air bubbles in the end product ("PET bottle recycling" 2013). When drying PET, a centrifuge is used in combination with a thermo heater which together bakes the PET until dry. An otherwise very common method is to use air dryers that use compressed airstreams to blow the granules dry.

Pelletizing

In order for the manufactured plastic product to have the highest possible quality and optimal material structure, it is highly important that the plastic that is being used during manufacturing have a uniform size. Since the plastic after shredding often is very uneven in size it is a common practice to melt and extrude the granules into a long and even string which is then cut into perfectly even pieces. This process is called pelletizing (Bozzelli, 2015).

Manufacturing or creating

With the recycled pellets as raw material, new products can be made through various manufacturing techniques. Again, the technique used depends on the application and on the shape of the product. One common manufacturing technique is injection molding (see Figure 5) where the plastic granules or pellets are loaded into a hopper and fed forward through a cylinder by a screw while being melted by heaters. The melt is then injected into a mold under high pressure. The mold is clamped together to maintain the pressure during cooling. After solidifying, the machine ejects the product and is ready to make yet another product.

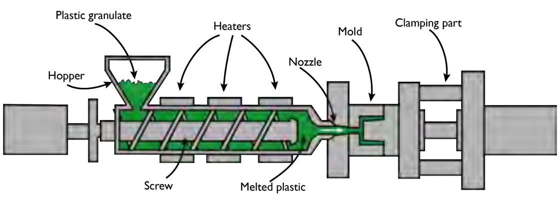


Figure 5. Schematic figure of an injection molding machine. Author's own copyright.

2.4 Simplified plastic recycling process

Several projects have been launched that simplify the industrial plastic recycling process with the purpose to raise awareness about plastic recycling and make it cheaper and more accessible to recycle plastic. This section takes a closer look at two of the projects that have had an impact on or inspired the Valuable Waste project.

2.4.1 Precious Plastics

One significant and proliferated project is the Precious Plastic project which originates from the Netherlands and has now grown into a global community of makers and creators. The purpose of this project is to make local plastic recycling affordable and easy for people around the globe (Precious Plastic, 2019). To reach that goal, the process and the involved machines have been simplified. The Precious Plastic project is open source and supplies anyone interested with information about the process and blueprints for the machines. One shredder and three creating machines (injection molding machine, extrusion machine and compression molding machine) are involved in the Precious Plastic process and are available online (Precious Plastic, 2019).

The plastic recycling process presented by Precious Plastic (see Figure 6) contains all important steps from the industrial process (i.e. collecting, sorting, shredding, washing, drying and creating). However, only the shredding step and creating step involves machines. Collecting and sorting are done manually. Regarding washing and drying the plastic, the solution for Precious Plastic is to collect only clean plastic. Furthermore, the pelletizing step is rationalized away, as the end products produced do not demand that high quality. Instead the manufacturing machines are fed with granules. Thus, the mechanical process that requires machines consists of only two steps; shredding and creating. In that way, the process becomes cheaper and more people are encouraged to join the fight against plastic pollution on site where the problem is. To sum up, Precious Plastic stands for a simplified approach towards plastic recycling. That is something that the Valuable Waste project learns from in order to make the otherwise complex and expensive plastic recycling process suitable for a science centre.

2.4.2 Perpetual Plastics Project

The Perpetual Plastic Project (PPP) is another plastic recycling initiative originating from the Netherlands (Perpetual plastic project, n.d). Unlike Precious Plastic, PPP is more focused on only raising awareness about the possibilities and necessity of recycling plastics. To do that, they have developed a plastic recycling exhibit that is compatible with fairs and temporary exhibitions.

Figure 6. Precious Plastic proposes a process where clean, dry and sorted plastic is collected. The shredding machine resizes the plastic waste to granules. The granules are then manufactured through one of the three creating machines to new products. Reprinted with permission.

The exhibit uses, as Precious Plastic, a simplified recycling process. The PPP process consists of four steps; cleaning, drying, shredding and creating. They invite people visiting the exhibit to bring their used bottles or disposable cups and then guide them through the steps. The bottle/cup gets cleaned, dried, shredded, extruded to 3D-printing filament and eventually 3D-printed to a plastic ring that the user can take home. In that way, the visitors can appreciate the plastic waste. The Valuable Waste project is essentially having very much the same values and goals. However, the science centre approach changes the target group and with it the outcome. Nevertheless, the PPP is an inspiration and a learning source for the Valuable Waste project.

2.4.3 Learning outcomes

By looking at Precious Plastic and PPP, our understanding for how the plastic recycling process can be altered and tweaked and still maintain its core functionality - create new things from plastic waste - is broadened. After analysing the industrial process, Precious Plastic and PPP, decisions can be made regarding which steps are needed in the process. Furthermore, insights can be drawn on how thoroughly the steps in the process must be carried out in order to make new things from plastic waste. For example, how crucial it is that the granules are shredded in even size or how clean and dry the plastic must be. Below are some of the most important insights listed:

- The most essential steps in the process are shredding and creating. However, this requires sorted, clean and dry plastic.
- Washing and drying are steps that are necessary in the industrial process. Since one of the goals of the exhibit is to educate about the plastic recycling process, these steps are preferably included in the exhibit.
- As long as the product that is to be manufactured at the exhibit does not put high demands on mechanical properties, it is possible to accomplish a plastic recycling process at a science centre.

The Precious Plastic and PPP are also used as references when evaluating if certain ideas might work or not.

3. Process

This project has entered three rather distinct phases as time has advanced (see Figure 7). These three phases will in the following chapter therefore be described individually with explanations of the methods used and a review on the approach in each respective phase.

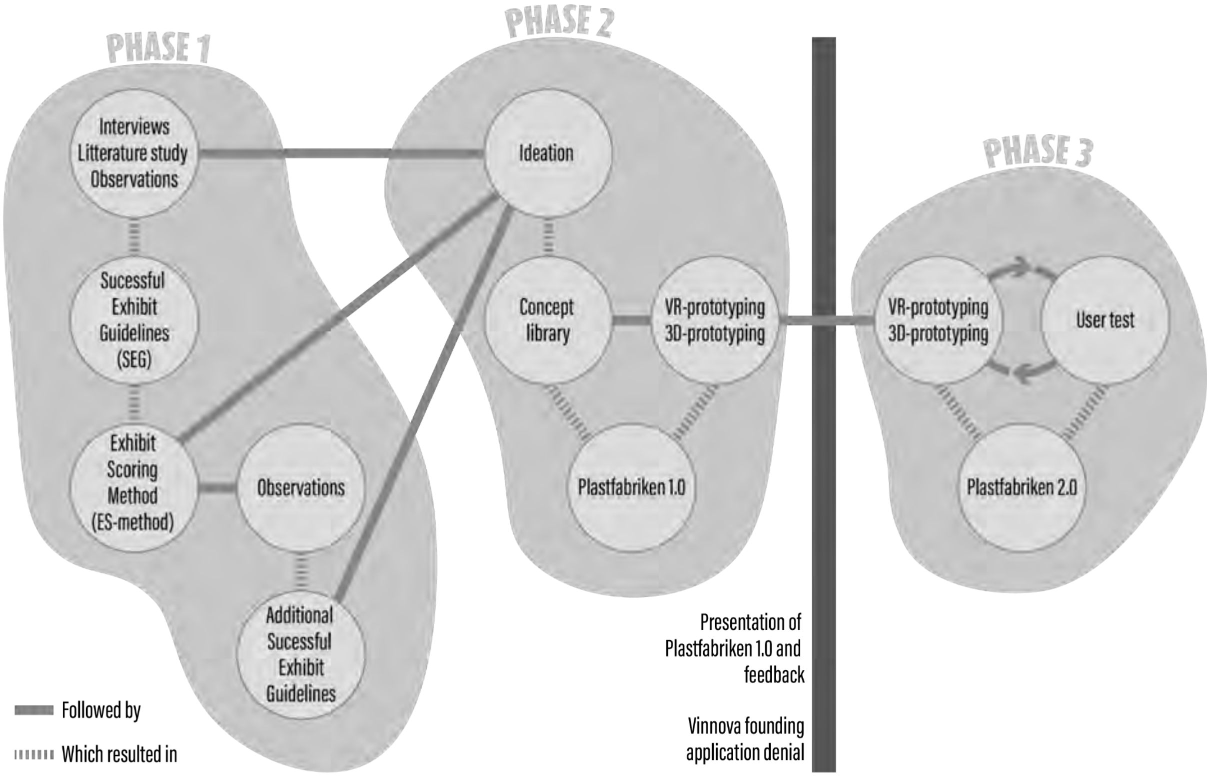


Figure 7. The project consists of three phases, where phase one is the study phase and phase two and three contains the concept development. The grey beam between phase two and three represents the midterm presentation and the denial from Vinnova, which led to a turn in the project.

3.1 Phase one

The project was initiated with a study on exhibit design where the first action was to visit science centres with the purpose of gathering relevant data of how exhibits are designed and to find answers to what it is that makes some exhibits more successful than others. This action and the methods used during it are what defines Phase 1 of the study. During the visits to science centres observations of user interaction and exhibit design were conducted. In addition, multiple interviews with exhibit designers were held to give insight and information about how exhibits are designed and things to think of when designing exhibitions and exhibits.

3.1.1 Observations

Observations were made at three science centres; Universeum in Gothenburg, Innovatum in Trollhättan and Experimentarium in Copenhagen. The reason for the observations was to collect relevant data regarding user interaction. However, the observations were also used to become more familiar with exhibit designs and the variation in design they can have.

At first, the collected data consisted of findings from rather unstructured observation where focus was the interaction between users and exhibits. The findings were gathered and made into design guidelines that would later be called the Successful Exhibit Guidelines (SEG).

3.1.2 Interviews

During phase one several interviews were conducted with the goal to collect data regarding exhibit design that experienced exhibit designers could provide. In total, four different exhibit designers (one from Universeum, two from Innovatum and one freelance working exhibit designer) were interviewed. All interviewees had at least five years of experience working as an exhibit designer.

When meeting with the exhibit designers, the interview usually started with a session where the designer answered prewritten questions in an open dialogue. The questions were followed up with a non-directive part where more of a free flowing dialogue took place. After that followed a tour of the science centre where the designers explained and spoke about the different exhibitions. At this point the questions were once again unstructured and were instead adapted to the situation. In addition, open structured interviews with twelve employees from all science centres were held. The questions concerned their perception of, and opinions about certain exhibits and attractions in regard to what exhibits seemed to be more popular and why.

3.1.3 Literature Study

The third method used to collect data was a literature study. It was conducted with the goal of collecting data that would contribute to finding more important design guidelines for creating a successful exhibit. The main approach was to read relevant scientific publications, academic journals and books. All digital technical reports were found using Google scholar's search engine, and some printed journals and books regarding exhibit design and user interaction borrowed from the library. A big part of the literature study was also to find relevant information regarding plastic consumption, people's view of plastic use, plastic waste management, environmental consciousness and information about the plastic recycling process.

3.1.4 Successful Exhibit Guidelines

After the first observations, interviews and literature study, the results were gathered into key findings of how to design an exhibit. The findings were translated into concrete guidelines that could be used during exhibit design to ensure it obtains a high quality result. The collection of guidelines is called the Successful Exhibit Guidelines and is made into a list, the SEG-list, (see Appendix IV). This list is divided into four categories; *design features, desired user experience, user engagement* and *things to avoid.* In every category, all SEGs are weighted compared to each other to ensure they get a rank corresponding to their importance. The SEG-list answers to what a successful exhibit should and should not consist of. *Design Features* is here shown as one example of how the four categories look (see Table 1). They are described more in depth in the results from Phase 1 (see section 4.4).

Table 1. A table with Successful Exhibit Guidelines in the *Design Feature* category.

[1.0]	**DESIGN FEATURES**
[1.1]	The user should be able to do stuff by themselves
[1.2]	The exhibit should contain things that users doesn't see in their ordinary life
[1.3]	The exhibit should involve as many parameters (senses) as possible
[1.4]	The exhibit should contain hands-on experiences
[1.5]	The visitors should be allowed and encouraged to touch and feel things
[1.6]	Utilize the muscle power of the visitors and use them as power input
[1.7]	The exhibit should encourage collaboration, between the users and their significant others
[1.8]	The interaction should be easy to use
[1.9]	The exhibit should effectively support collaboration
[1.10]	The exhibit should be designed to minimize the need for signs with extensive text chunks
[1.11]	The exhibit should effectively support interaction.
[1.12]	The interactive stations should reset to default position independent of the visitors

Every guideline within their respective category from the SEG-list has been weighed against the others according to a weighting matrix. Since not all guidelines are equally important, applying weight to them will yield a more accurate guide to how to create a successful exhibit design. The weighting matrix is created by placing the same guidelines along both x- and y-axis and then one by one answering whether one is more or less important than the next one. The matrix is completed by reading top-down, starting with: "is [1.1] more (1), less (0) or equally (0,5) important as [1.2]?". Followed by: "is [1.1] more (1), less (0) or equally (0,5) important as [1.3]?" and so on.

Table 2. The weighting of the guidelines in the *Design Feature.*

	[1.1]	[1.2]	[1.3]	[1.4]	[1.5]	[1.6]	[1.7]	[1.8]	[1.9]	[1.10]	[1.11]	[1.12]	SEG weight
[1.1]		0.5	1	0.5	1	1	1	1	1	1	0.5	1	9.5
[1.2]	0.5		1	0.5	0.5	0.5	1	0	1	1	0	1	7
[1.3]	0	0		0	0	0	0.5	0	0.5	0.5	0	1	2.5
[1.4]	0.5	0.5	1		0	0.5	1	0.5	0.5	0.5	0	1	6
[1.5]	0	0.5	1	1		1	1	0.5	1	0.5	0	1	7.5
[1.6]	0	0.5	1	0.5	0		0.5	0.5	1	1	0	1	6
[1.7]	0	0	0.5	0	0	0.5		0.5	0.5	0.5	0	1	3.5
[1.8]	0	1	1	0.5	0.5	0.5	0.5		1	1	0	1	7
[1.9]	0	0	0.5	0.5	0	0	0.5	0		0.5	0	1	3
[1.10]	0	0	0.5	0.5	0.5	0	0.5	0	0.5		0	1	3.5
[1.11]	0.5	1	1	1	1	1	1	1	1	1		1	10.5
[1.12]	0	0	0	0	0	0	0	0	0	0	0		0

The rest of the SEG are weighted the same way as the example shown above (see Table 2).

3.1.5 Exhibit Scoring-Method

It was realized after the creation of the SEG-list that the observations had the possibility to yield even more SEG if a more structured and systematic approach was used. Therefore the Exhibit Scoring-method (ES-method) was developed. With it, the data collection is conducted in a structured and scientific way and an exhibit's success rate can be determined. By being able to determine the success rate of an exhibit, the exhibit design can be analyzed and strengths and weaknesses of the exhibit can be found.

The ES-method is divided into two parts. The first part is a quantitative data collection where the science center visitors and their interaction with the exhibit is measured. The data is collected from five (or more) measurement occasions with 20 minutes apart. The results of this first part of the ES-method is summarized into three different categories. They are: *Gender diversity, Even points of interaction (POI) attractiveness* and *Level of engagement* (see appendix II for more information about the ES-method). The second part of the ES-method is about answering what level the exhibit accomplishes to follow the SEG and is, as the SEG-list, divided into the four categories; *Design features, Desired user experience, User engagement* and *Things to avoid.* When conducting the ES-method this part is done by evaluating how well the exhibit accomplishes each SEG according to a 1-5 scale, where 1 is "not at all" and 5 is "completely". Once completed, all categories of the ES-method will be given a final score between 0-1 which will correspond to how well the guidelines in this category are met. A value of 1 would mean the highest score and that the exhibit is perfectly designed according to that category. A value of 0 would mean the opposite. The exhibit will also be given a final ES-rating determining how successful its design is.

Having the ES-method divided into these seven categories enables a feature where one is able to backtrack and pinpoint where and why an exhibit has received its score. If, for example, the *Desired user experience* category scores poorly, specific analysis of the experience of the exhibit can be conducted in order to find areas of improvement..

3.1.6 Observation using ES-method

After the development of the ES-method, additional observations on Universeum, Innovatum and Experimentarium were conducted in order to test the ES method, determine the exhibits' ES-rating and to collect data in a more structured and scientific way. The observations followed the steps found in the method. The second part of the ES-method was done by examining the exhibits and as precise as possible give it a rating between 1 and 5 according to how well they accomplish the SEG.

3.1.7 Defining the exhibit

Phase 1 of the process ended with a survey called "Exhibit Characteristics". The survey was conducted in order to categorise and define different approaches the design of the exhibit could take. From the observations, interviews and literature study a framework for categorizing exhibits was found. The framework consists of three characteristic scales. The three scales that are used to categorise different exhibits are **manned** (M) or **unmanned** (U), **real** (R) or **symbolic** (S) (where **real** represents a real plastic recycling process and **symbolic** means showing the process flow by using for example multicolored balls) and lastly **playground** or **industrial**, in a six grade scale where 1 describes a feeling of playfulness and 6 describes a feeling of laboratory. By answering these three measures, the examined exhibit will be given a score that explains which design approach it uses. To better understand the possible outcomes of this method, two extreme-scores were defined. Manned, real and laboratory (MR6) and Unmanned, symbolic and playful (US1). In the case of determining the approach of the exhibit, a scoring of US1 would be a kind of playground only showing the flow of the plastic recycling while the one scoring MR6 would resemble a laboratory environment where pre-booked school-kids could bring plastic waste and do a supervised "recycling session".

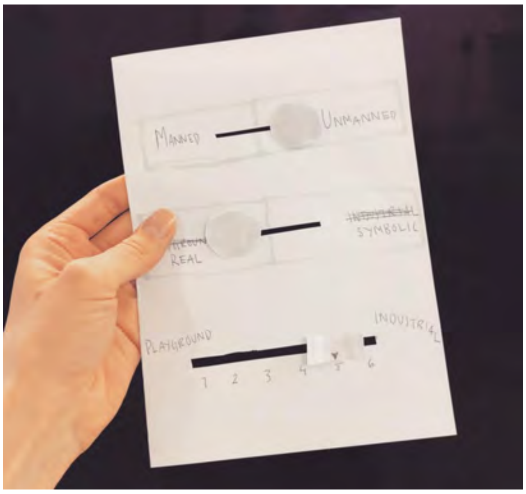


Figure 8. A form developed to gather the stakeholders' mental image of the exhibit.

The method was used to try and find the stakeholders' mental image of what design approach the exhibit should have. This was done by handing out a simple yet effective form which they could fill in (see Figure 8). The stakeholders were one exhibit designer and one manager for sustainable business at Universeum, one researcher from CIT and six designers from Boid.

All stakeholders were presented four different possible results to give them a better understanding of how the mental image form worked. They were:

1. UR2: A recycling factory that is running all the time. Everybody can interact and affect the flow via interfaces but the visitors will not have the possibility to touch the actual material.

2. MURS16: Basically both extremes in the same exhibition. The exhibit would be divided into two sections, one playful area where the plastic recycling process is explained by having balls acting in a recycling system with lots of points of interaction and one manned laboratory area where the users can experiment with recycling plastic.

3. MR4: This version could be called "*the school project*". Pre-booked classes can experience the exhibit that would consist of a working recycling process.

4. UR5 A Laboratory-feeling with some restricted interactions making it possible for the user to take part of the process.

The survey was answered by the stakeholders, which were the employees at Boid and the staff responsible for exhibits at Universeum.

3.2 Phase two

The project's second phase is characterized by ideation and concept creation of the exhibit design. With the knowledge, data and information gathered in phase one it was possible to develop relevant ideas that later could be turned into working concepts. Because of the exhibit's complexity, the amount of the produced concepts quickly became too large to handle efficiently. Because of this it was decided that all concepts were to be categorised and ordered in a structured library. The library was designed to consist of a bigger supra-system that should contain subsystems. The library was called the *concept library* and would be used to more efficiently store, sort and evaluate the produced concepts. It would later also help improve the development of a final exhibit design concept.

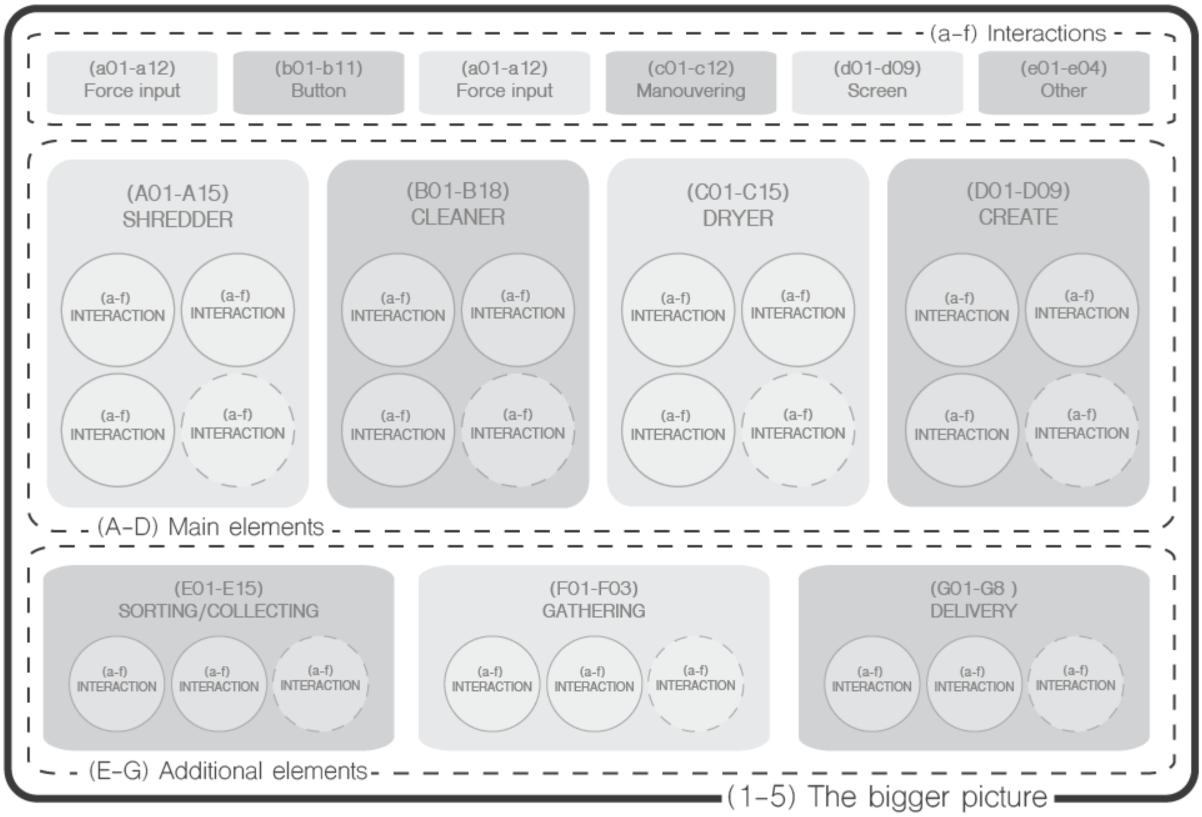


Figure 9. The Concept Library

3.2.1 Creating the concept library

The concept library was created to make sense of and organize the vast solution space that the scope of the project allowed. In the concept library, the exhibit is broken down into four categories; *Bigger picture, Main elements, Additional elements* and *Interactions* (see Figure 9). To produce a complete final exhibit design, concepts from all categories are needed. The final exhibit design should consist of one from all *Bigger pictures* (1-5), one from all *Main elements* (A-D), some/none/all of *Additional elements* (E-G) and the Main- and Additional elements should contain *Interactions* (a-f).

Bigger picture

The bigger picture is a term for describing the overall spatial features of the exhibit. It is the highest level in the idea hierarchy and is not concerned with details. However, it will affect the possibilities for ideas on the lower levels. Hence, *the bigger picture* sets the borders and delimits the solution space for the design of the elements.

Main elements

Main elements refer to the elements needed to perform the steps, they are directly connected to the plastic recycling process. The study of the industrial process, Precious Plastic and Perpetual Plastic Project, led to the decision of which elements should be considered *Main elements*.

Additional elements

Additional elements consist of steps in the process that function as indirect steps, supporting the recycling process. Those are sorting/collecting, gathering and delivering.

Interactions

This category refers to all concepts regarding the interactivity of the main and additional elements. The interaction category is divided into subcategories to distinguish them.

3.2.2 Filling the concept library

The concept library was filled through ideation sessions and one workshop. The ideation sessions consisted of brainstorming, speed storming (Wikberg et al., 2015) and the Lotus Blossom method (Delalande, 2019).

The workshop was held with four participants from Boid, excluding the project group. The participants were briefed on the problems and in a first step asked to brainstorm around the washing and sorting elements. In a second step, ideation around three out of four main elements (washing, drying, creating) was conducted. In the second step, a slightly altered Brainwriting 6-3-5 method (Wikberg et al. 2015) was used. The participants were asked to, in six minutes, sketch three (one per element) ideas on an A3 paper and then send it to the right neighbour. In five minutes, the participants were then asked to develop the ideas that their left neighbour had initialized and then send it to the right neighbour. This was repeated until each participant got their initial paper back.

The above mentioned methods were used to fill the concept library. However, through rational deliberation, some of the ideas were discarded before entering the concept library due to lack of quality and potential. The ideas that made it into the library were then developed and sketched at the same level of detail in order to make them comparable in further concept eliminations.

3.2.3 Morphologic analysis of the concept library

The top three concepts in each main and additional element category (A-G) in the concept library were selected through concept elimination (see Figure 10). The elimination resulted in finding the top concepts from all main element categories. This was done using Pugh's decision matrix (Burge, 2009).

Figure 10: Top scoring concepts from all Element categories (A-G).

Since rating all concepts against all SEG was not reasonable due to the extensive time it would take, it was decided to only use the top scoring SEG from all four SEG-categories in the decision matrix. These were then weighed against each other (see table 3).

Table 3. The most important SEG from each category are weighted against each other.

	The user should be able to do stuff by themselves	The elements should utilize and encourage the creativity and imagination of the visitors	The visitors should be allowed and encouraged to touch and feel things	The element should generate aha-moments	The exhibit should effectively support interaction	A too complexed goal	Children should learn from the element	The exhibit should be self explanatory	Children should find the learning experience enjoyable	Weight
The user should be able to do stuff by themselves		0.5	1	0.5	0	1	1	0.5	0.5	5
The element should utilize and encourage the creativity and imagination of the visitors	0.5		1	0.5	0	1	0	1	0	4
The visitors should be allowed and encouraged to touch and feel things	0	0		0	0	1	0	0	0	1
The element should generate aha-moments	0.5	0.5	1		0	1	0.5	1	0.5	5
The exhibit should effectively support interaction	1	1	1	1		1	0.5	1	0.5	7
A too complexed goal	0	0	0	0	0		0	0.5	0	0.5
Children should learn from the element	0	1	1	0.5	0.5	1		0.5	0.5	5
The exhibit should be self explanatory	0.5	0	1	0	0	0.5	0.5		0	2.5
Children should find the learning experience enjoyable	0.5	1	1	0.5	0.5	1	0.5	1		6

By using these SEG as the requirements in the decision matrix to weigh all element concepts against, it was possible to define the best scoring concepts. Table 4 below shows the elimination for category A, which contains the concepts for the shredder element. In this elimination, A13 scored highest, A14 second and A12 third. A10 and A15 were sorted out beforehand due to lack of quality or potential.

Table 4. The concept elimination for the shredding element.

	weight	A01 (datum)	A07	A08	A09	A10	A11	A12	A13	A14	A15
The user should be able to do stuff by themselves	5	0	-5	-5	-5		-5	0	0	5	
The element should utilize and encourage the creativity and imagination of the visitors	4	0	4	-4	4		0	0	4	4	
The visitors should be allowed and encouraged to touch and feel things	1	0	-1	0	0		-1	0	1	0	
The element should generate aha-moments	5	0	5	0	-5		-5	0	5	0	
The exhibit should effectively support interaction.	7	0	0	-7	7		7	7	7	7	
A too complexed goal	0.5	0	0	0.5	0		0	0	-0.5	-0.5	
Children should learn from the element	5	0	-5	0	-5		-5	0	5	-5	
The exhibit should be self explanatory	2.5	0	2.5	2.5	-2.5		2.5	0	-2.5	0	
Children should find the learning experience enjoyable	6	0	6	0	6		6	6	0	6	
		0	6.5	-13	-0.5	0	-0.5	13	17	16.5	0

By repeating this process for all element categories - the top three concepts from every category were found. By choosing one concept from every main and additional element category (A-G), a finished exhibit design could be developed. By having eliminated most concepts and only doing this selection from the top scoring ones, it was made sure that the exhibit design would achieve high quality. Three different exhibit designs were produced by combining different concepts from the top scoring ones. The first one was the *High Score Exhibit*. This consisted of the highest scoring concept from all main element categories. The second exhibit design was the *Feedback Favourite exhibit*. This consisted of the concepts that received the best feedback when the concepts were presented to Boid. Lastly was the *Industrial Exhibit* which consisted of the concepts that were most similar to the industrial recycling process . Out of these three exhibit designs, the *Feedback Favourite Exhibit* was decided to be developed further.

3.2.4 Development of Plastfabriken 1.0

What followed was an iterative process of what was going to become the first finished concept of the plastic recycling exhibit - later called Plastfabriken 1.0. Since there was no budget for the project - at this point the project group still waited for an answer for the funding application - the prototyping and development was primarily made in digital form. The iterative process consisted of two steps; design and evaluation. The design was made in the 3D program *Cinema 4D,* where the early concept sketches were transformed to 3D prototype models. For evaluation, the 3D models were exported to *Unity,* an application with support for Virtual Reality (VR). With VR, the 3D models of the different elements were evaluated. The evaluation did not follow any specific structure but included focus areas as, for example, layout of Points of Interaction (POI), size, design language and overall impression.

3.3 Phase three

Entering phase three means a turn in the project, a new concept generating phase, concept testing and user test.

3.3.1 Refining and rethinking

The start of phase three is distinguished by the receiving of the decision from the Vinnova funding application. The application was turned down which forced the project group to rethink how to find funding from other sources for the project. In addition, during the same time a mid thesis presentation was held for Boid. The presentation showed some of the study results and its findings together with the results from the concept library. This was also the first time Boid was introduced to the finished exhibit design concept (i.e. Plastfabriken 1.0). Plastfabriken 1.0 got the feedback of being too "sci-fi" and unrealistic. It lacked anchoring in relation to a budget.

These two turns of events initiated a rethinking of the current design and the development of Plastfabriken 2.0. The exhibit design had to be developed to be more realizable but also have a lower estimated manufacturing cost. The concepts in the library could be weighted differently, according to the feedback, and thus new high-scoring concepts could be picked. In addition, concepts like the ManWash (B15) and the Floor Sprinkler (C15) from Plastfabriken 1.0 were further developed into new similar but more realizable and less costly elements in Plastfabriken 2.0. ManWash became Washing Drum (B19) which is based on the same thinking with a water tank and a spinning drum while Floor Sprinkler maintained its name but the size of it was drastically decreased. From the newly formed concepts combined with new high-scoring ones from the concept library, Plastfabriken 2.0 started to take shape.

3.3.3 Proof of concepts

This section explains some of the testing that was conducted in order to explore the feasibility of certain ideas.

Making transparent granules more visible

Due to Plastfabriken 2.0 only processing PET bottles, the vast majority of the granules will be transparent. This will, in some of the elements, run the risk of decreasing the user experience. For example in the washer, if the granules are not visible enough, some of the user information exchange will be lost. To solve this, a visibility test was conducted to confirm the assumption that shining beams of light into the water would make the granules more visible. In the test granulated PET was put in a container filled with water. A spoon was used to imitate turbulence in the water, making the granules swirl around. A comparison between the non lit (see Figure 11) and lit (see Figure 12) set up show that shining light will make the granules somewhat more visible.

Figure 11. Non Lit water bath show that the granules are hard to see without lighting.

Figure 12. Hitting the water bath with light which is reflected by the granules, resulting in them being more visible.

Drying wet granules using stream of high pressure air

A test to confirm the possibility of drying wet granules by blowing streams of high pressure air was conducted by wetting granules and then blowing at it with a high pressure nozzle. The wet granules were put in a strainer and on top of it different sizes of various kinds of chambers. Figure 13 shows the testing of how well granules were blown through a pipe as a method of transportation.

Figure 13. Testing the feasibility of transporting wet granules using high pressure air.

Ergonomics and interaction tests

Various crude, simple and non-costly prototype testing was conducted to verify or determine different design solutions such as sizes, heights, accessibility and user experiences. The radius of the crank's rotational path is here tested using two clamps and a rod (see Figure 14).

Figure 14. Testing the feel of the crank's dimensions by using woodworking clamps and a tube.

3.3.4 User test

In order to evaluate the final concept, a user test was conducted. Four general questions were formulated to frame what information was desired to elicit from the participants. These four questions then served as a foundation for the design of the user test. The four questions were: I. *Was the task understood?* II. *Was the exhibit fun to interact with?* III. *Did the users learn anything from the exhibit?* IV. *Was the exhibit suitable for 11-year olds?* The user test was conducted in virtual reality (VR).

Preparations

A script based on the four questions was made to make sure that relevant information could be extracted from the test and also to make the different tests comparable. The script was used as a guide for the test. Probing questions was used beside the script in order to elicit further information. Plastfabriken 2.0 was then modeled in the 3D program Cinema 4D. The model consisted of the complete intended design including Points of Interaction (POI). To make the proposed use of the exhibit clear, the model was animated so that the participants in the user test could see and follow a bottle through all steps in Plastfabriken 2.0 including how the respective POI was supposed to function. Further, a credible environment for the exhibit was modelled. The context for Plastfabriken 2.0 is science centres, and more specifically Universeum. Thus, the environment was created so that the participants could get a sense of walking into one of the exhibitions in Universeum. It consisted of a room inspired by the room where the exhibition "Hälsan" is currently housed. Plastfabriken 2.0 was placed in the middle of the room while the rest of the room was filled with placeholders that were designed to give the impression of being part of the exhibition (see Figure 15). In order to facilitate the guidance of the participants during the test, colorized dots were placed on the ground at desired spots, for example in front of every POI (see Figure 16). In that way, the test leader could lead the participants by telling them to move to a specific dot.

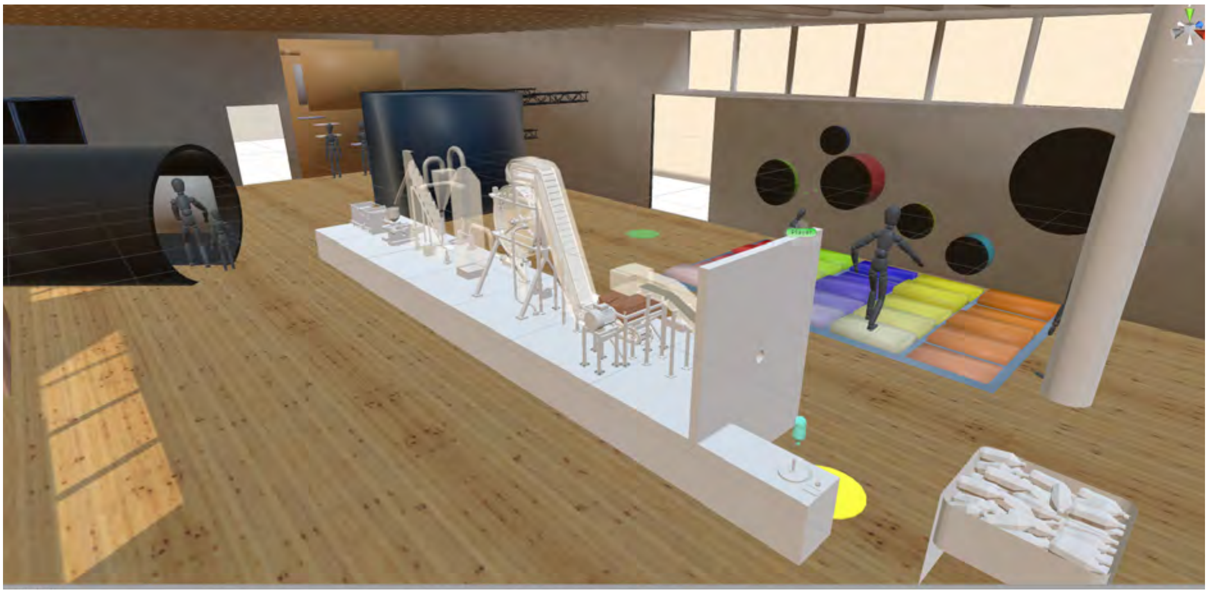


Figure 15. Screenshot from the user test environment that was inspired by the exhibit "Hälsan" at Universeum.

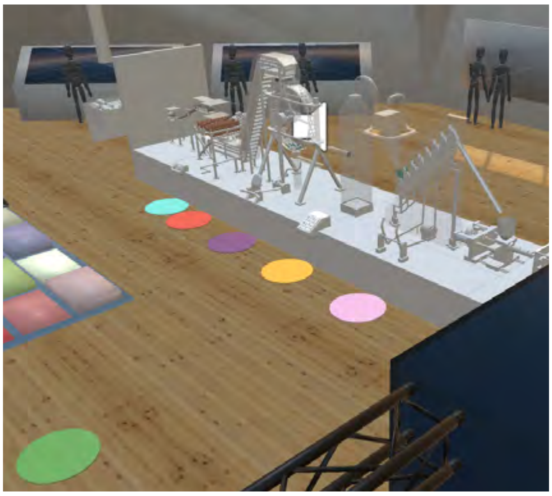


Figure 16 . Screenshot from the user test environment. Colorized dots functioned as guides for the test user.

Participants

The participants were all parents, which was intended. In that way, data could be collected both regarding what the participants themselves experienced but also what they thought their kids would have done in the same situation. There were four participants of which three were designers and the fourth a business developer. All participants had former experience of being in VR.

Implementation

Each test was controlled by a test leader from the project group. The test leader guided the participant and also asked the pre written questions from the script. Furthermore, the test leader tried to elicit more interesting information by asking probing questions in response to what the participants said. During the complete test, notes were taken by another member of the project team. The test consisted of two parts. In the first part of the test, the participants were asked to answer how they believed their kids would act. In the second part, the participants answered for themselves. These two parts were separated in the script, but in the tests they were much intertwined for convenience reasons. The participant was in VR for the entire test. When he or she entered the created environment, they were placed outside the room. As a first step, the test leader ensured that the participants knew how to move around in the VR environment. When the terms for that were established, the participants were invited to enter the room and move to a spot where he or she had a good overview of the room in general and, in particular, Plastfabriken 2.0. Here, they were asked about the first impression regarding appearance and which part that was perceived as most attractive. After that the participants were guided through every step of Plastfabriken 2.0. At each step, he or she was asked to describe what they (and their child) thought to be the goal of the respective element. Further, they were asked what kind of emotions they felt and how they would have interacted with the element if they could. At the end of each session at corresponding element, an animation that showed how the interaction worked was played for the participants. The test took 20-25 minutes per participant.

3.3.5 User test analysis

By reading and interpreting the raw data from the user test, four themes could be discerned from the participants' answers. Thus, the results from the user test were broken down into four categories; *design proposals, user actions, emotions* and *analyses*. *Design proposals* included quotes and thoughts from the participants that regarded the design. *User actions* contained the responses when the participants encountered the POI, element or exhibit. The *emotions* category encompassed the feelings evoked within the participant during the test. Finally, the *analyses* category consisted of analytical thoughts expressed by the participants. The quotes and answers from the participants were then put into one of these categories (see Appendix I). This structure made it easier to overview the results. The user test results were then further analysed. This was made by answering the four questions (see 3.3.4) with the quotes from the participants.

3.3.6 Finalising and scoring Plastfabriken 2.0

From the user test results, a new iteration of development and refining of Plastfabriken 2.0 began. The user test results were considered and valuable for the continuation of the project. However, all results could not be implemented in the development. Previous experience, gathered knowledge and the feasibility aspect was used by the project team to determine which results could be implemented in this phase of the project.

Plastfabriken 2.0 was then scored using the ES-method. The evaluation was made based on the user test and on the 3D model of the exhibit. The first part of the ES-method that requires quantitative data from observations of the exhibit in use, could not be filled in accurately since Plastfabriken 2.0 is a concept. Instead, assumptions were made that this part would reflect the scoring on the second part that evaluates the exhibit regarding the SEG-list. That means that if the exhibit for example scores moderately on the second part, it would also score moderately on the first part.

4. Phase one results

This chapter presents the results found in phase one that consists of the outcome of the Exhibit Scoring method (ES-method) and the Successful Exhibit guidelines list (SEG-list). By conducting the ES-method, exhibits with high ES-rating could be distinguished and analysed to find additional guidelines. The analysis from these exhibits and the results it gave are also provided in this chapter. The last section in this chapter summarizes the insights from phase one in a vision that works as a goal during the remaining phases of the project.

4.1 Defining the exhibit

The results from the Exhibit Characteristics survey showed that the stakeholders' mental images in general were very similar. The result can be summed up in a scoring of **UR4** (see Table 5).

Table 5. The results from the survey showed that all participants prefer an unmanned, real working plastic recycling exhibit.

Manned: 2	Unmanned: 7
Real : 9	Symbolic: 0
Playful or Laboratory: average 3,6	

The stakeholders' mental image of the exhibit could therefore be summarized to be an *Unmanned, Real working* exhibit with a design language showing that it is an industrial process but still keep the playful feeling from a science centre.

4.2 Successful Exhibit Guidelines

In order to create a successful science centre exhibit one must know what the definition of a successful science centre exhibit is. The literature study and interviews were conducted to define this. The collected data were compiled and resulted in the Successful Exhibit Guidelines list (SEG-list) (see 4.3).

4.2.1 Analysing and extracting guidelines from the study

The guidelines are based on data and insights gathered in the observations, interviews and literature study. Below are analysis from these events described.

Literature study

The study on exhibits in the literature gave important insight and knowledge to incorporate as guidelines. In their paper, Hall & Bannon (2006) evaluates how novel technology can be implemented to enhance the learning experience for children at museums. They concludes the paper with 12 guidelines that can be applied on museums but also on other "educational environments". Some of the guidelines seemed relevant for science centres and were compared to the results from the interviews and observations which were more to the point applicable for science centres. If confirmed and supported in the interviews and observations, the guidelines, and other information from Hall & Bannon (2006) were used as a base for some of the SEG. Two examples are the SEG [2.1], "The exhibit should consist of storytelling and narrative creation" and SEG [2.4] which reads "children should find the learning experience enjoyable".

Observations

The first observations contributed to general insights of the science centre context as well as a general understanding of the users and how they interact with the exhibits. Thus, the first observations did not give any guidelines directly. However, together with the ES-method, further observations gave basis to more SEG (see 4.5.2).

Interviews

The interviews were important as the gathered data came from people with hands-on experience of designing exhibitions. Many of the guidelines are drawn from these interviews. For example, the first interview with an exhibition designer at Innovatum in Trollhättan provided basis to eleven guidelines that during further study were confirmed by other interviewees, observations and literature study.

4.3 Successful Exhibit Guidelines list

In table 6, the complete list of SEG is presented. The guidelines are divided into four categories. Those categories are described below. It is important to stress that these guidelines do not consider the safety aspect, since those aspects are covered in rules and regulations. It is also worth noting that all guidelines are not applicable at all stages of the design process. Some of the guidelines cannot be applied nor evaluated without thorough and extensive user tests with high resolution prototypes.

Table 6. The complete Successful Exhibit Guidelines list. The guidelines derive from literature studies (L), observations (O) and interviews (I).

[1.0]	**DESIGN FEATURES**
[1.1]	The user should be able to do stuff by themselves. (L, I, O)
[1.2]	The exhibit should contain things that users don't see in their ordinary life. (L)
[1.3]	The exhibit should involve as many parameters (senses) as possible. (L)
[1.4]	The exhibit should contain hands-on experiences. (L, I, O)
[1.5]	The visitors should be allowed and encouraged to touch and feel things. (L, O)
[1.6]	Utilize the muscle power of the visitors and use them as power input. (L, O)
[1.7]	The exhibit should encourage collaboration between the users and their significant others. (L, O)
[1.8]	The interaction should be easy to use. (L, I, O)
[1.9]	The exhibit should effectively support collaboration. (L, O)
[1.10]	The exhibit should be designed to minimize the need for signs with extensive text chunks. (L, I, O)
[1.11]	The exhibit should effectively support interaction. (I, O)
[1.12]	The interactive stations should reset to default position independent of the visitors. (O)
[2.0]	**DESIRED USER EXPERIENCE**
[2.1]	The exhibit should consist of storytelling and narrative creation. (L)
[2.2]	The exhibit should elicit laughter. (L, I, O)
[2.3]	The exhibit should generate aha-moments. (I, O)
[2.4]	Children should find the learning experience enjoyable. (L, O)
[2.5]	The exhibition should utilize and encourage the creativity and imagination of the visitors (L)
[3.0]	**USER ENGAGEMENT**
[3.1]	The exhibit should be self explanatory (I, O)
[3.2]	Children should be actively interpreting material culture for themselves. (L)
[3.3]	Children should learn from the exhibit. (L, I, O)
[4.0]	**THINGS TO AVOID**
[4.1]	The design of the exhibition should not resemble inappropriate things (eg fallo). (L, I)
[4.2]	Avoid nooks where visitors can hide things. (O)
[4.3]	The exhibit should not include loose theft-prone objects. (O)
[4.4]	The exhibit should not include loose objects. (O)
[4.5]	The amount of needed staff supervision should be kept at minimum. (I, O)
[4.6]	If signs are necessary, they should not score higher than 30 according to LIX. (L, O)
[4.7]	Avoid passive and voiceless material interpreting. (L)
[4.8]	The exhibit should not be perceived as frightening. (L)
[4.9]	The exhibit should be easy to understand. (L, I, O)

4.4 Explanations of guidelines

This section provides explanations of the categorisation of the guidelines. It also elaborates on the most important guidelines of each category.

4.4.1 Design features

This category provides guidelines for what features the interplay between the exhibit and user should contain. In general, these guidelines point out the importance of the exhibit to encourage, invite and support the user in the interaction with the exhibit and in the collaboration with other users. Further, the guidelines in this category strive to challenge the exhibit designer to develop things that are intriguing for the users to interact with but also to observe. The three most important are:

- [1.9] *The exhibit should effectively support interaction* - Interactivity is a crucial part of the experience and learning aspects. Letting users actually push the button or pull the lever, invites them to take an active part in the learning process.
- [1.1] *The users should be able to do stuff themselves* - This guideline strives to stress the importance of giving users the feeling of being in charge of the events that are controlled through a certain POI.
- [1.5] *The users should be allowed and encouraged to touch and feel things* - It is important that the visitors feel that they do not need to feel restricted but instead encouraged in their curiosity and exploratory minds.

4.4.2 Desired user experience

It is important, from an educational perspective, that the user associates the exhibit with positive emotions (Wills, 2007). If an experience is enjoyed and positively remembered there is a bigger chance that the knowledge will be remembered and transformed to behavioural change. The guidelines in this category, thus, focus on the internal experience of the user. The most important are:

- [2.3] *The exhibit should generate aha-moments* - A sudden enlightenment, within the user, that is elicited by the exhibit contributes to lasting knowledge and an uplifting experience.
- [2.4] *Children should find the learning experience enjoyable* - A science centre experience should be something beyond the ordinary learning experience from school that preadolescents are used to.
- [2.5] *The exhibition should utilize and encourage the creativity and imagination of the visitors* - 11-year-olds, who are the main target group for Universeum, are at a stage in life where creativity and imagination play vital roles for their development. The exhibit should utilize these traits and encourage them by ingenious challenges.

4.4.3 User engagement

These guidelines can in a way be considered to be the consequences of other fulfilled guidelines. In other words, if the guidelines in for example the *design feature* category are considered, these guidelines could function as a verification. The two most important are:

- [3.3] *Children should learn from the exhibit* - This is the main reason why most science centres exist, thus an important guideline. To reach this goal, it is likely that other guidelines, especially in the *Design features* category, must be fulfilled.
- [3.1] *The exhibit should be self explanatory* - This guideline is closely related to, for example [1.1] and [4.9]. That is, the users should be able to approach any POI, understand it by looking at it (the POI could possibly contain signs if necessary) and use it.

4.4.4 Things to avoid

Since science centres are well visited places where everyone is welcome, there are certain things to avoid. By doing that, chances increase that the users can focus on the things that the exhibit is designed to make them focus on. The most important are:

- [4.9] The exhibit should be easy to understand - Avoiding a too complex task of a POI makes it more probable that the user does not get stuck or bored. The level of complexity should be well balanced for the target group.
- [4.5] *The amount of staff supervision required should be kept at minimum* - This ties into guideline [1.1] and [3.1] and contributes to that the user feels in charge of the situation and not controlled. The latter can lead to a fear of making mistakes.
- [4.6] *If signs are necessary, they should not score higher than 30 according to LIX* - Note that the formulation of this guideline implies that the design of the exhibit should be designed so that as few signs as possible should be used. But if there must be signs, LIX, which is a readable index system, is a good tool to make sure the signs are readable.

The SEG-list is used to ensure a relevant and successful development of the exhibit and is furthermore implemented in the ES-method. The ES-method is in turn used to rate other exhibits as well as evaluating the final concept in this project.

4.5 ES-rating

The Exhibit Scoring method (ES-method) was created to collect quantitative data from observations in a systematic and scientific way. The ES-method is designed in a way so that any science centre exhibit can be observed and given a score which determines its level of success. Conducting the ES-method while observing active exhibits at Universeum, Innovatum and Experimentarium resulted in defining the exhibits' level of success which then made it possible to point out the most and the least successful exhibits. The features found in the successful exhibits could then be used to ensure that the outcome of this project will be successful.

4.5.1 Top ES-scores on observed exhibits

This chapter provides the scoring from the three top rated exhibits and an analysis of the reasons for the scoring. This analysis is part of the basis for the SEG, which is described in 4.4.

Figure 17. Hälsan is an exhibit at Universeum, Gothenburg.

Hälsan, Universum

The *Hälsan* exhibit (see Figure 17), translated to Health, is an exhibit where the users try various forms of physical activities and receive body and health related information. Examples of activities are time measuring chin bar, height measuring jump camera and healthy teeth quiz.

Table 7. Hälsan scored 141.3 out of 210 points which yields a value of 0.67. The full ES-rating can be found in Appendix IIIA.

	Score	Max score	Avg.	Weight	IES	Max	%
Gender diversity	-	-	8,6	2	17,2	20	0,86
Even POI attractiveness	-	-	6	2	12	20	0,6
Level of engagement	-	-	9,1	2,5	22,75	25	0,91
Sum (Users & POI)	-	-	-	-	51,95	65	0,8
DESIGN FEATURES	237,5	330	7,2	5,5	39,6	55	0,72
DESIRED USER EXPERIENCE	26,5	50	5,3	4,5	23,9	45	0,53
USER ENGAGEMENT	7,5	15	5	3,5	17,5	35	0,5
THINGS TO AVOID	149	180	8,3	1	8,3	10	0,83
Total					**141.3**	210	**0.67**

Hälsan is a huge exhibit consisting of 21 POIs in total. It has great scores for both gender diversity and level of engagement (see Table 7). This means it has been developed to be designed for all and succeeded very well. The lower score on *Even POI attractiveness* is due to the difference in popularity between the POIs. The most popular ones were where the users were activated and the learning experience was through physical activities. One reason for that is that those activities attracted spectators to try. The least popular ones focused more on the information and contained chunks of texts. Regarding the SEG, Hälsans score is lowered substantially by its low ability to accomplish a good user experience. This is mostly due to the lack of elements that generate aha-moments [SEG 2.3] (see 4.4). However, Hälsan scores overall well and is a popular exhibit at Universeum.

Figure 18. Circus Fysikus is an exhibit at Experimentarium, Copenhagen. The spinning disk (in the middle) is a popular POI.

Circus Fysikus, Experimentarium

The Circus Fysikus exhibit (see Figure 18) is an experimental exhibit with focus on explaining and showing physical phenomena such as pulley systems, gearing, rotational forces and more.

Table 8. Circus Fysikus scored 165.8 out of 210 points which yields a value of 0.79. The full ES-rating can be found in Appendix IIIB.

	Score	Max score	Avg.	Weight	IES	Max	%
Gender diversity	-	-	6	2	12	20	0,6
Even POI attractiveness	-	-	4,8	2	9,6	20	0,48
Level of engagement	-	-	9,5	2,5	23,75	25	0,95
Sum (Users & POI)	-	-	-	-	45,35	65	0,7
DESIGN FEATURES	280,5	330	8,5	5,5	46,8	55	0,85
DESIRED USER EXPERIENCE	44,5	50	8,9	4,5	40,1	45	0,89
USER ENGAGEMENT	11	15	7,3	3,5	25,6	35	0,73
THINGS TO AVOID	141,5	180	7,9	1	7,9	10	0,79
Total					**165.8**	210	**0.79**

One of the most popular POIs at Circus Fysikus was a rotating disc (see Figure 18) that the users could put various things on. Provided at the POI were rings and billiard balls. The users could experiment with the centripetal force and how the linear velocity varies depending on the radius, by trying to get the rings and balls spinning in a sweet spot so that they stayed on the spinning disk. The reason for its popularity was due to the users' opportunity to experiment themselves and that they were urged to, by trial and error, figure out how to find the sweet spot. Furthermore, it seemed to exceed the users' expectations when they interacted with it. POI that were not so popular failed due to a weak goal description or that the learning experience was long winded. Circus Fysikus had indeed some clear user favourite POIs and some that were not used much at all. This made it score only 0,48 on the *Even POI attractiveness* (see Table 8). It generally scored great at the SEG categories, this was mostly because it showcased interesting experiments which intrigued a lot of users. It had good design in terms of giving the user a high degree of freedom while interacting with the POIs. The high scoring on aha-moment is mostly due to the combination of showcasing classical mechanical problems and letting the users play around with them until they understand how it works. This arguably elicits sudden moments of enlightenment.

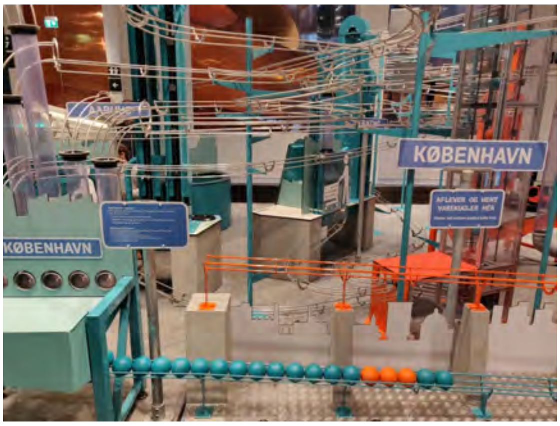


Figure 19. Hamnen is an exhibit at Experimentarium, Copenhagen.

Hamnen, Experimentarium

Hamnen (see Figure 19) is an exhibit that aims to show how different means of transportation around the world leads to different amounts of carbon dioxide emissions. It consists of a huge system of piping where balls, each with a printed symbol representing different types of cargo, travel across the globe (symbolically), by either boat, train or aeroplane. The learning lies in how much physical effort the user has to put into sending the cargo with the different modes of transport. Sending it by plane requires more physical effort than sending it by train. Thus, the intended learning is that a plane emits more CO_2 than a train does.

Table 9. Hamnen scored 146.2 out of 210 points which yields a value of 0.7. The full ES-rating can be found in Appendix IIIC.

	Score	Max score	Avg.	Weight	IES	Max	%
Gender diversity	-	-	7,2	2	14,4	20	0,72
Even POI attractiveness	-	-	9,2	2	18,4	20	0,92
Level of engagement	-	-	9,6	2,5	24	25	0,96
Sum (Users & POI)	-	-	-	-	56,8	65	0,87
DESIGN FEATURES	219	330	6,6	5,5	36,3	55	0,66
DESIRED USER EXPERIENCE	29,5	50	5,9	4,5	26,6	45	0,59
USER ENGAGEMENT	8,5	15	5,7	3,5	20	35	0,57
THINGS TO AVOID	117	180	6,5	1	6,5	10	0,65
Total					**146.2**	210	**0.7**

Hamnen is an example where the scores of the Users and POI categories are very high (0,87) (see Table 9). The reason for this is probably the holistic take on the exhibit. The POI in themselves were not that remarkable but they were many and all contributed to the same goal; to transport the balls from one place to another. But the exhibit does not score well in the SEG categories. The idea of the exhibit is strong but the execution is a bit off. The users rarely grasped the fact that the entire exhibit was about the environmental impact of global transportation. The perception during the observations was that the playfulness stole the focus from the intended learning outcomes. Hamnen had two other distinct drawbacks. One was that the symbols on the balls were torn off, which made it more difficult to fulfill the task. Another was that some tasks, where the users should follow the instructions on a touch screen, were too time consuming, which resulted in an uncompleted task. However, Hamnen has a very high level of engagement and integrality because it has user friendly and easy-to-understand POIs with a result that is fun and intriguing (a ball that goes through long distances of piping in exciting loops and swirls). The intriguing and appealing appearance of Hamnen is also crucial to its popularity.

4.5.2 Additional SEG from ES-rating analysis

The analysis of the highest scoring exhibits resulted in the uncovering of additional SEG (see Table 10). The new SEG cover aspects that did not come forth in the initial study. Many of them (SEG [2.6], [2.7], [1.12], [1.13]) touch upon the critical moment when the users begin to interact with the exhibit. If the exhibit fulfills those guidelines, the chances increase that the users stay at the POI until the task is accomplished. The last two guidelines (SEG [1.14] and [3.4]) strive to increase the exhibit's attraction to the visitors. In summary, these new guidelines complement the SEG-list by covering aspects that did not appear in the initial study.

Table 10. This table contains the SEG that were found from the analysis of the ES-rating of existing exhibits.

	After analysis of highest scoring exhibits
[2.6]	Low amount of time should be needed to understand the task
[2.7]	The thrill of engaging with the exhibit should correspond, or exceed, the perceived expectations
[1.12]	If the task of the exhibit is complex - the purpose must be well defined and easily interpreted
[1.13]	The exhibit should function properly
[1.14]	The exhibit should elicit wow-moments
[3.4]	The exhibit should attract spectators to become users

Besides the new SEG, the ES-rating gave insights about how a societal issue can be addressed through a science centre exhibit. Both Hälsan and Hamnen target important questions that modern civilisation struggles with. Hälsan's goal is to enlighten people about the human body and how important it is to embrace a healthy lifestyle. It does so by using the most obvious tool; the users' own bodies, which is a powerful solution. Hamnen tries to change peoples' view on fossil fuels and the environmental benefits when choosing other means of transportation than aviation. It does so by letting the users transport "cargo balls" from A to B. Choosing aeroplane as means of transportation demands more muscle input, choosing the train requires less muscle input. That is indeed an educative and well thought out approach. This kind of issue requires symbolic means as it is not feasible in any other way. However, it seemed like the playful design of the exhibit possibly hindered the users to understand or remember what the meaning behind the exhibit was. From these insights, it seems very powerful to address the issue with peoples' view on the value of plastic with an exhibit that is able to actually recycle plastic waste and make something valuable from it. The fact that a new product is made facilitates for the users to remember what the exhibit is about.

4.6 Vision

In order to have a clear goal of what to achieve in the project, the insights from the study phase were gathered in a tangible target or vision that could be pursued. The vision contains all crucial parameters that will affect the outcome and sets a framework for the process. In this section, the exhibit is referred to as "Plastfabriken" as the vision targets both Plastfabriken 1.0 and Plastfabriken 2.0.

Plastfabriken should be an exhibit that makes up the centrepiece of a larger exhibition at Universeum. As a centrepiece, it should be awe-inspiring and attractive to observe. It should, moreover, draw the attention of the visitors to make them want to explore it. Anyone visiting Universeum should be able to and inspired to interact with it, however, the main target group is the same as for Universeum, that is 11 year-olds. What is extraordinary with Plastfabriken is its ability to perform a plastic recycling process. It should be able to process the user's plastic waste and, by the input from the user, make something new and valuable. The goal with Plastfabriken is, in addition, to design it so it can be operated unmanned, meaning no staff from Universeum should be needed for it to function. The user input and an automated system should be enough. This would make it possible for the users to interact with Plastfabriken in a free and playful manner, learning at their own pace without any pressure from a grown up watching over them. In this way, Plastfabriken would affect the users and create sparks of incentives that in the end will lead to a changed view on plastic waste, as something valuable that should be treated correctly and with respect.

5. Phase two results

The results produced in phase two consisted solely of design concepts for the Plastfabriken 1.0 exhibit. The results refer back to the ideation sessions that were conducted during phase two and hence this chapter will aim to give an insight into what results that can be found in the concept library.

5.1 Concept library

The following section presents the results from the concept library. The concept library consists of four categories. Those are: *bigger picture, main elements, additional elements* and *interactions.*

5.1.1 The bigger picture

This section provides descriptions of different *bigger pictures* of the exhibit. Five bigger picture concepts were proposed and developed, those are described below.

The Wall (I)

The Wall (see Figure 20) consists of all elements in the process mounted on a wall. This allows for a pedagogic understanding of the process and can be designed as a flowchart. The spatial spreading allows for several interaction points through the process. See Table 10 for pros and cons.

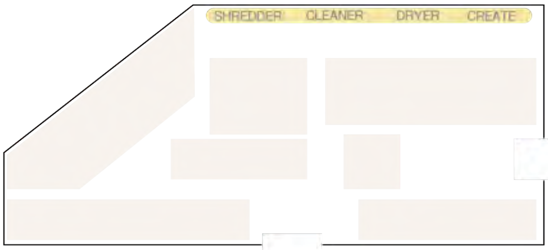


Figure 20. Example of how the bigger picture "The wall"

Table 10. Pros and cons with The Wall.

Pros
• *Pedagogic and comprehensible view of the process.* • *Provides a good overview of the process.*
Cons
• *Restricted to physically smaller interactions.* • *Less potential as a conspicuous centrepiece of the exhibit.*

The Scattered (II)

One of the "bigger picture" concepts is based on the idea of having the elements scattered throughout the exhibit area (see Figure 21). The elements are connected through various means of transportation. Having the elements scattered will work as a glue for the whole exhibit, tying the entire exhibit area together. Furthermore, it will mildly force the visitors to visit all parts of the exhibit. See Table 11 for pros and cons.

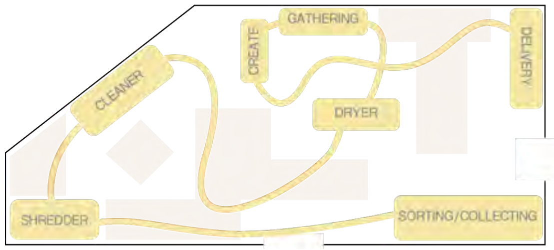


Figure 21. Example of how the bigger picture "The Scattered"

Table 11. Pros and cons with The Scattered.

Pros
• *Great possibilities for visual magnificence* • *"Wow-feeling"* • *Binds the exhibit together* • *Possibilities for great variations in interaction*
Cons
• *Might be difficult to get an good overall picture of the recycling process*

The Constricted (III)

In The Constricted concept the elements are, unlike The Scattered, placed close to each other and hence the transportation parts are not a significant part of the visual experience (see Figure 22). See Table 12 for pros and cons.

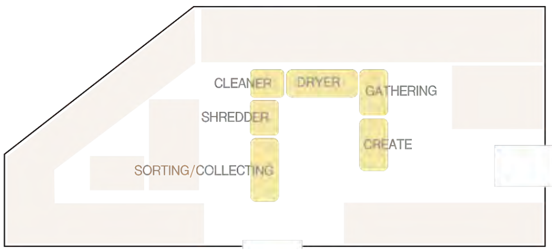


Figure 22. Example of how the bigger picture "The Constricted"

Table 12. Pros and cons with The Constricted.

Pros
• *Gives the visitors a pedagogical overview of the process*

• *A great centrepiece of the exhibit* • *Enables for study visits with for instance school classes.*
Cons
• *Restricted room for interactions*

The Broadcasted (IV)

This concept utilizes the whole science centre and its elements are supposed to be placed all over the building (see Figure 23). For example, the shredder on the first floor, the cleaner on the second floor, etcetera. They are connected through various transportation systems that guide visitors to the different elements where various interactions can be placed. See Table 13 for pros and cons.

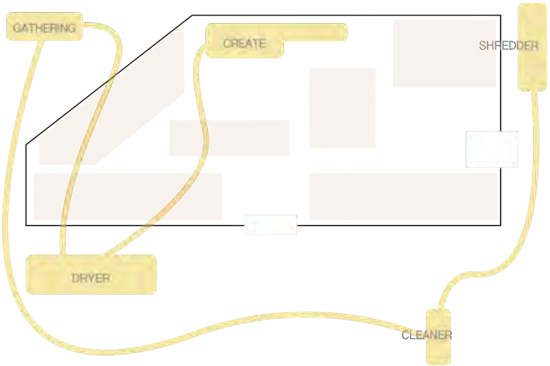


Figure 23. Example of how the bigger picture "The Broadcasted"

Table 13. Pros and cons with The Broadcasted.

Pros
• *Creates an exciting environment for the science centre* • *Can be placed to ensure that the visitors visits the whole science centre*
Cons
• *No clear overview of the process*

The Unit (V)

The Unit is inspired by reverse vending machines or vending machines. It contains all necessary components for a plastic recycling process but packaged in a compact box-like unit (see Figure 24). The idea is that the user puts plastic waste in the unit input, pushes one or several buttons or other interaction elements, and then receives a remade plastic thing as output. See Table 14 for pros and cons.

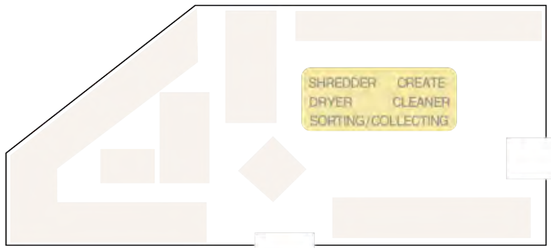


Figure 24. Example of how the bigger picture "The Unit"

Table 14. Pros and cons with The Unit.

Pros
• *Compact and space efficient design* • *Easy to use* • *Versatile and flexible; could be put up anywhere in public areas and not only in science centres*
Cons
• *Not suitable for exhibits to the same extent as other bigger pictures* • *Users can put in whatever trash they want and jam the machine* • *Hides much of the process*

5.1.2 Main and additional elements

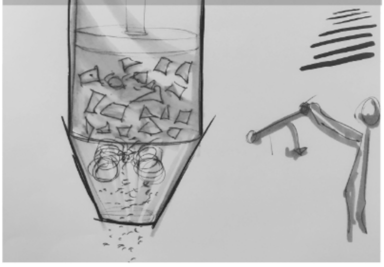
Both Precious Plastic and Perpetual Plastic Project use simplified versions of the industrial process. They differ due to their slightly different purposes. Precious Plastic's proposed process only contains shredding and creating. The rest of the steps are done manually. The Perpetual Plastic Project's process, on the other hand, contains cleaning, drying, shredding and creating. Both projects contain shredding and creating, which can be considered to be the most basic and important steps, directly connected to the plastic recycling process. The Perpetual Plastic Project has, due to their orientation towards fairs and exhibitions, a similar approach to the plastic recycling process as the Valuable Waste project. Thus, *Main elements* consist of (A) shredding, (B) washing, (C) drying and (D) creating. Regarding the *Additional elements,* Sorting/collecting are bunched together because of the possibility of doing both steps in the same element. However, not all concepts in this category are combined. Gathering and delivering are elements that are not present in the industrial process but added due to their compatibility with science centre exhibits. The gathering element is supposed to gather the granules, both when waiting for the creating element, but also to make it visible for the visitors. Furthermore, during special events, supervised visitors could be allowed to touch and feel the granules. Thus, the gathering element is much of a possible educational element. The delivering element is supposed to take the created plastic and display it in some way. These elements are denoted as (E) sorting/collecting, (F) gathering and (G) delivering. Table 15 shows the complete element section (i.e. *main* and *additional elements*) of the concept library. Page 25 and 26 shows the top three scoring elements from each category. Each element is presented by a sketch and a short description.

Table 15. The table shows the element section of the concept library.

ELEMENTS													
(A) Shredding		**(B) Cleaning**		**(C) Drying**		**(D) Creating**		**(E) Sorting/collecting**		**(F) Gathering**		**(G) Delivery**	
01.	Horizontal shred	**01.**	The wavemaker	**01.**	Weight cupol shooter	**01.**	The X-ray	**01.**	Floor rec-center	**01.**	Spec corner	**01.**	Plinger
02.	The Knifer	**02.**	The lava square	**02.**	Silo spiral blow	**02.**	Waffel Iron	**02.**	Trash bin	**02.**	Wall mount	**02.**	Water Cooler Bath
03.	The Vertinder	**03.**	Puzzle wall	**03.**	Silo Upward blow	**03.**	Personal Creation	**03.**	Sorting Arm	**03.**	Plastic caruselle	**03.**	Catapult
04.	The Chopper	**04.**	Jumping water	**04.**	Vacuum cleaner	**04.**	Pull Hatch ManStrude	**04.**	Conveyor Loop			**04.**	The Slider
05.	The Stamper	**05.**	Waterwheel	**05.**	Air Shooter	**05.**	Digital inputer	**05.**	Sort by Figure			**05.**	The Gondoler
06.	The Tearer	**06.**	Tube spiral	**06.**	The Flipper Fan	**06.**	Lever Chooser	**06.**	Marble Dropper			**06.**	Tube to store
07.	Floor Shred	**07.**	Waterfall	**07.**	High blower Tube	**07.**	MegaMicro Molder	**07.**	Harvest Sorter			**07.**	Conveyor Pusher
08.	Super Hero Shred	**08.**	Mega Water Brush	**08.**	Hot Air Flow Oven	**08.**	Sheet Vaccum	**08.**	Leveltrash			**08.**	Canon Eject
09.	Blow Up	**09.**	Manual Dishing	**09.**	Towel Wiper	**09.**	Man-weighted inj.	**09.**	Hatch-scan				
10.	Center Piece	**10.**	Fire Truck Hoose	**10.**	Jumping Laminar	**10.**	Injektor	**10.**	Plastfab. trach center				
11.	The Harvester	**11.**	Water Slide	**11.**	Jet Canon			**11.**	Density bath				
12.	The Silo	**12.**	Curling	**12.**	Heater			**12.**	Trans. shop bin				
13.	CoOpShred	**13.**	HPW-clean	**13.**	Cube dryer			**13.**	Auto Scanner				
14.	The crane	**14.**	HPW-HPA (combo)	**14.**	Tornado								
15.	The hatch drop	**15.**	ManWash	**15.**	Floor sprinkler								
		16.	Swirlmaker										
		17.	Washingmachine										
		18.	Water tornado										
		19.	WashingDrum										

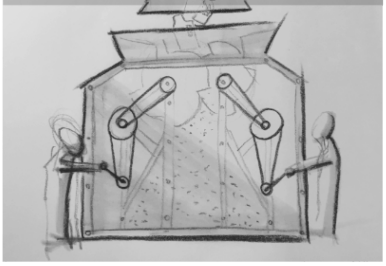
SHREDDING (A)

The Silo



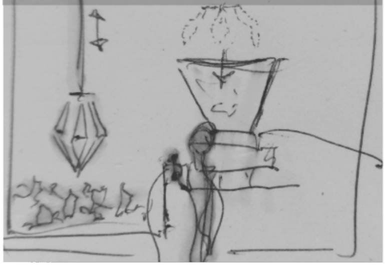
In this concept, the shredder is built into the end of a large cylindrical tube. The plastic waste is thought to enter at the top of the tube and the user maneuvers the feeding of the plastic waste by controlling a crusher, pressing the waste through the shredder.

The CoOpShred



This concept utilizes the idea of having the operation of the shredder being manpowered. By turning the two crankshafts, the users will rotate the shredder's blade and thus shred the plastic.

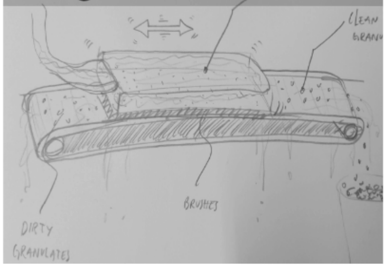
The Crane



In this concept, the plastic waste is placed into the shredder by the use of a 3-axis claw controlled by the user.

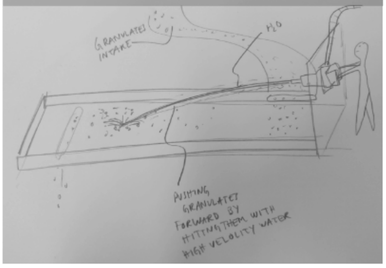
WASHING (B)

Mega Water Brush



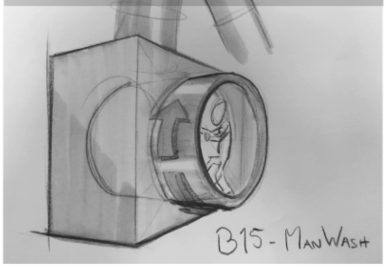
The idea was to let the granulate pass under a large washing brush that by shaking and pressing down on the granulate while releasing water would clean the granulate from residue and impurities.

Fire Truck Hoose



In this concept the granulates are cleaned by being sprayed with high velocity water. To ensure the granulate would be hit with enough quantity of water, the users task is to move the granulate the to the exit by hitting it with the water and thereby at the same time - cleaning it.

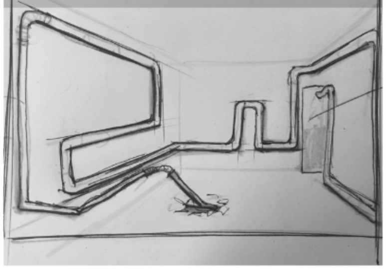
ManWash



The idea behind the ManWash came from a ordinary washing machine. With a container partly filled with water and a manpowered drum that could throw the water around, cleaning the granulates.

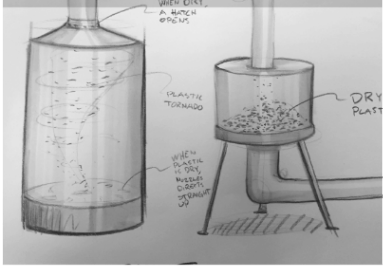
DRYING (C)

Vacuum Cleaner



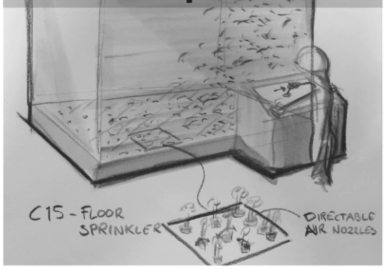
The thought of letting the granulates dry using strong wind resulted in the idea of using a vacuum system, much like a vacuum cleaner. The user would use a manouverable handle to suck up wet granulate. The granulate would then dry while passing through the long system of tubes.

Tornado



Using directable air nozzles integrated in the bottom plate, the user would control the nozzles angle, thus creating a tornado looking phenomenon with the granulates. The granulates would dry because of the hot strong winds from the nozzles.

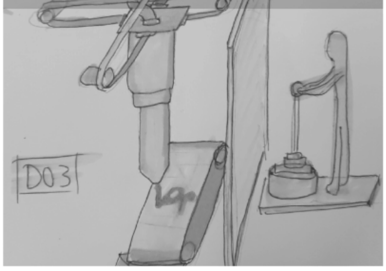
Floor Sprinkler



The granulates enter on the left side of the big chamber and is pushed around by hot air nozzles in the bottom plate. The goal is to move the granulates to the exit outlet by controlling the nozzles. The strong hot air will dry the granulates as it is being tossed around in the chamber.

CREATING (D)

Personal Creation

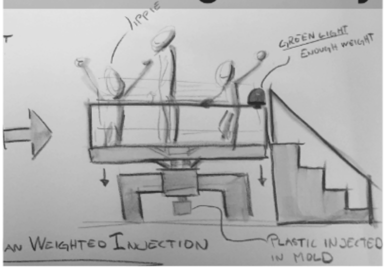


In this concept, the user is allowed to create their own parts by steering an extruder attached to a 3-axis system. The idea could be compared to a huge 3D-printer where the user is in control of the printer head's movement.

Digital Inputter

With the digital inputter, the user is able to control an injection molding machine using a digital interface. The user is able to choose from different molds and colors to create their personal molded plastic part.

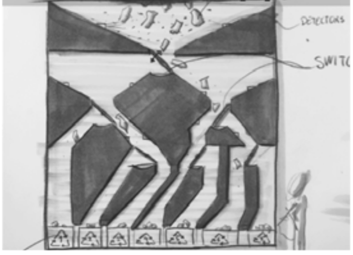
Man-Weighted Inj



In this concept, the users will step onto a platform that when enough weight has been added (total weight form the users on the platform) will transfer the downward force to the pressing force needed for an injection mold.

SORTING/ COLLECTING (E)

Marble Dropper

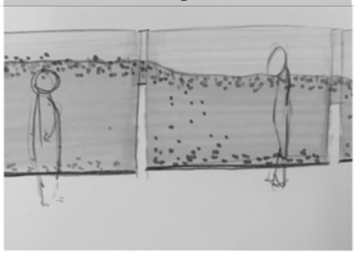


The sorting mechanism in the Marble Dropper consists of an infrared camera detecting what kind of plastic that enters. The machine then directs the hatches along the way to place the plastic waste in its correct bin.

Hatch Scan

When scanning your own brought plastic using the IR-camera rig, the corresponding hatch for that specific type of plastic will open.

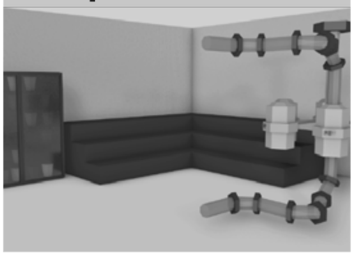
Density Bath



Most plastics have different floating capabilities. By having a series of baths with different liquid density, certain types of plastic will stay float and others will sink. From this idea came the Density bath as a concept of sorting plastics.

GATHERING (F)

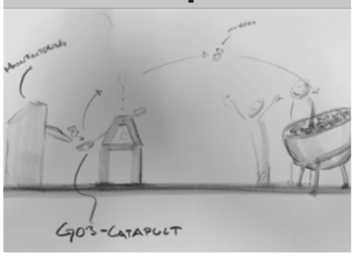
Spec Corner



The Spec Corner is an educative zone where visitors can be lectured during specific hours. This place contains granulate that is gathered in buckets to showcase and let the visitors touch and feel the plastic.

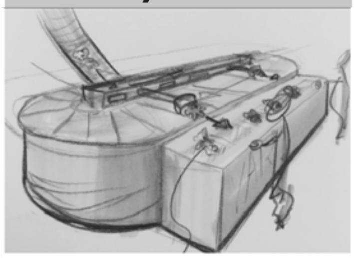
DELIVERING (G)

Catapult



To deliver the molded part in a fun way, the part is here loaded onto a catapult after being molded. Once loaded, the catapult then launches the part in a parable, ending in a large bucket filled with other parts that the user now can pick from.

Conveyor Pusher



After being molded, the part is placed on a conveyor going around a table. The only way for the user to get hold of the molded part is, by using a joystick with perfect timing, push the part off the conveyor and into reach.

Canon Eject

Much like the Catapult concept, the molded part is here launched over the exhibit user audience and lands in a basket of other molded parts ready for the user to grab one.

5.1.3 Interactions

Table 16 shows the different categories and concepts of interaction that were developed during this phase. Below is a description of each category provided.

Table 16. The table shows the element section of the concept library.

INTERACTIONS											
(a) Force input		(b) Button		(c) Maneuvering		(d) Screen		(e) Passive control		(f) Other	
01.	Rotational wheel	01.	Rotational knob	01.	Linear lever	01.	Touchscreen	01.	Pulse meter	01.	Voice Control
02.	Linear lever	02.	Push button	02.	Hatch	02.	Cylinder Screen	02.	Body placement	02.	3D Modeling
03.	Bicycle wind	03.	Slider knob	03.	Joystick	03.	AR-Screen	03.	Camera scanning	03.	Phone Control
04.	Rope pull	04.	Jelly Button	04.	Waterhose	04.	Giant Touchscreen	04.	Heat Cam	04.	Mind Control
05.	Stair walking gym	05.	Squeeze Hug Button	05.	Transport materia	05.	VR	05.	Fart Control		
06.	The Teeter	06.	SameTimeButt	06.	Sand Box	06.	Xray-Projection	06.	The Mechanical Nose		
07.	Spinning doors	07.	Laser Beam	07.	MMX Prog-Wheel	07.	Cupol Screen	07.	Weight Scale		
08.	Rope Slap	08.	Flick Switch	08.	Eye Tracking	08.	Floor Screen	08.	Motion Tracking		
09.	The Punch Bag	09.	Floor Button	09.	Bucket Fill	09.	Physical Screen Control	09.	Theremin		
10.	Bicycle	10.	Giant Slider	10.	Grid Control			10.	Eye Scanning		
11.	Thor	11.	ShiningGreenStartButton	11.	Gate Control			11.	Distance Tracking		
12.	Ski Cross			12.	Pipe Gate Control						

Force input (a)

The *Force input* interaction-category consists of concepts where the user interaction is based on force transmissions. The user is able to affect the actions of the element by, in different ways, applying force via the POI.

Button (b)

b01-b11 are all different button-focused concepts. How the POI can be designed using buttons in various assemblies, sizes or embodiments.

Maneuvering (c)

In the maneuvering category are concepts consisting of different ways for the user to experiment, alter or modify by different means. These POIs are intended to let the user have a high degree of freedom in what is possible to do.

Screen (d)

Screens are a typical way for a user to interact with a product. These concepts show how a screen based POI can take shape.

Passive control (e)

In the *passive control* category are concepts where the user interacts using properties of the body, such as using the body's weight, pulse or placement.

Computational (f)

These concepts all require some sort of computational processing where the user interacts by the use of for example voice or mind.

5.1.4 Creating the exhibit design concept

From evaluating the five bigger picture concepts, it was concluded that The Constricted, The Scattered and The Broadcasted can be considered as three versions of the same concept. The only thing that differentiates between them is the transportation from one element to the next. So whether the elements are placed next to each other or "broadcasted" all over the building, the elements can be the same but the transportation must be very different. Combining the three concepts to one creates a very strong and versatile concept that conquers the remaining concepts. Therefore, one bigger picture was not chosen for the final design but instead the idea of letting the elements be modular and have the possibility to be placed best suited for the environment.

From the 83 element concepts, the top three within each element category were appointed using the Pugh matrix. From these, in total, 19 concepts, three final design solutions were created. The *High Score Exhibit*, the *Industrial Exhibit* and the *Feedback Favourite Exhibit*.

The High Score Exhibit concept consisted of the one concept scoring the absolute highest score in every element category. A13, B08, C14, D03, E09, G(03,07,08).

Figure 25. All concepts included in the High Score Exhibit

The Industrial Exhibit consisted of the concepts that had the most similarities to how the industrial plastic recycling process looks. A14, B(01,06), C03, D05, E11

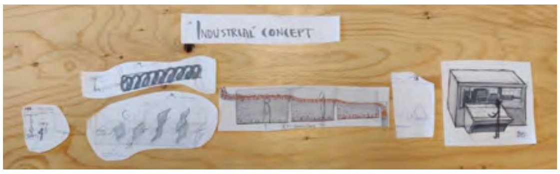


Figure 26. All concepts included in the Industrial Exhibit

The Feedback Favourite Exhibit consisted of the concepts that were considered to be the favourite ones out of the 19 top scoring concepts. A13, B15, C15, D09, E09, G07.

Figure 27. All concepts included in the Feedback Favourite Exhibit

Out of these three final design concepts, the Feedback Favourite Exhibit concept was chosen as the concept to further develop into the final exhibit design. All three concepts that survived the Pugh matrix had great potential. However, with all knowledge and experience from visiting exhibits, the project group considered the Favourite concept to be the most inspiring one to work with.

Figure 28. An overview of Plastfabriken 1.0. The seven elements are placed as *scattered* regarding the bigger picture.

5.2 Plastfabriken 1.0

The following section contains description and explanation of Plastfabriken 1.0 (see Figure 28), a concept to the plastic recycling centrepiece at Universeum. It is developed to meet the guidelines in the Successful Exhibit Guidelines list (SEG-list). No consideration regarding the budget has been made. With that in mind, Plastfabriken 1.0 can be considered to function as inspiration and an example on how the SEG-list can be embodied. This concept is also taking into consideration that Plastfabriken 1.0 should be "*an unmanned real working plastic recycling exhibition that has the opportunity to offer more features during a planned visit with a supervisor*" which was determined using the Exhibit Characteristics survey [3.1.7].

5.2.1 Overview

Plastfabriken 1.0 is in essence a plastic recycling industry that has been cross-fertilized with a science centre exhibition. Thus, it is a place where plastic waste gets sorted, shredded, washed, dried, melted and manufactured into new valuable things. Plastfabriken 1.0 consists of seven main elements, appurtenant interactions and transportation for the plastic material between the elements.

The plastics with the six first RIC can be recycled in Plastfabriken 1.0. Users are invited to bring their own plastic waste. They are then guided through the process where their waste becomes new things. Furthermore, the users are engaged and push the process forward by exciting and fun interactions. However, in order to meet SEG 1.12 and ensure a fail-safe unmanned process that is not dependent on the users, the involved elements are to a necessary degree automated. The following sections will contribute with more in-depth descriptions of each of the seven elements.

5.2.2 Main elements

The seven main elements of Plastfabriken 1.0 consist of the necessary steps that are needed in the plastic recycling process. Each element is designed to be safe to operate and interact with, limiting the risk of injury or machine failure. The following pictures of the elements, however, do not show the safety measurements but instead focus on highlighting the appearance and design.

Cleaning

This element is the first in Plastfabriken 1.0. Its purpose is to make sure that the waste that is to be processed is clean from residues and dirt so it can be processed by the elements in the exhibit.

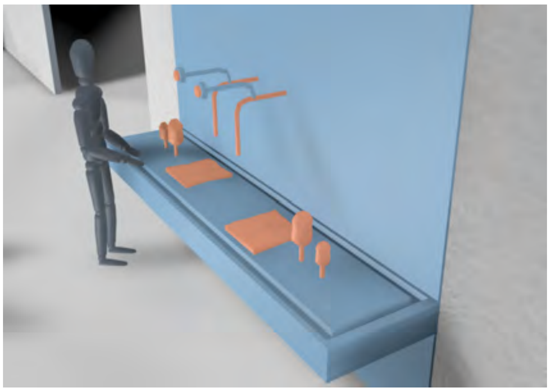


Figure 29. The cleaning station in Plastfabriken 1.0

Element description

The cleaning element (see Figure 29) is completely manual and consists of a sink with various cleaning equipment. The element includes water supply and mounted sponges suitable for bottles, jars and other plastic waste.

User interaction

This element offers hands-on experiences and highlights the fact that plastic waste must be cleaned in order to be recyclable. The users are urged to wash their waste with available means. This element gives the users insights about the necessity of cleaning their waste at home and thus connects to SEG 2.3; 3.3. Furthermore it is straightforward and easy to understand and use (SEG 1.8; 3.1). Further development can be done to meet the guidelines that involve enjoyment and wow-moments (SEG 1.14; 2.4).

Sorting - Auto Scanner

This step is a crucial step in the plastic recycling process. Since different polymers have different melting temperatures, mixed polymers can cause problems during the manufacturing process.

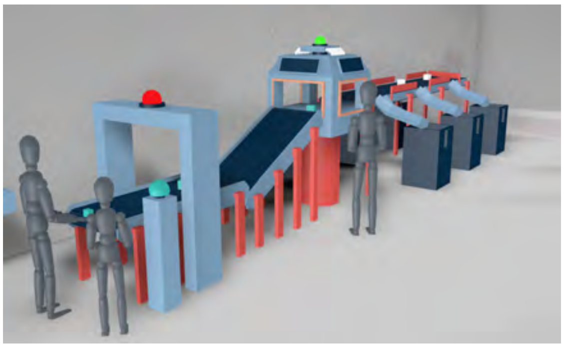


Figure 30. The sorting station in Plastfabriken 1.0

Element description

The sorting element (see Figure 30 is referred to as the Auto Scanner in the concept library and utilizes a scanning technique that is used to identify plastic materials. The Auto Scanner is to a great extent automated to ensure that nothing but the right plastic material is put into the right bin. The scanner is the most important part of the element and is situated in the middle, raised up to a level that makes it more visible for the spectators. Its purpose is to determine whether objects put into it are made of compatible materials. To do that it performs a scan of the current object that identifies the wavelength of the material and from that it determines if it is an approved plastic or not. Furthermore, the Auto Scanner consists of three conveyor belts; the first is available for the users to put their waste on, the second is slanted in order to bring the waste up to the scanner, and the third, arranged after the scanner, is equipped with gates that guide the waste to the corresponding bin. There are six bins, one for each plastic. Further, the element is equipped with a portal, marking a border for the users not to pass. Lastly, the interaction part is a user controlled start button that initializes the scanning and sorting procedure.

User interaction

The users are invited to put their plastic waste on a conveyor belt and push a button to start the process. The conveyor belt brings the plastic waste into the scanner which determines what polymer the current object is made of. If the scanner detects other material but plastic or if more than one polymer is detected, the conveyor belt reverses and brings the object back to the user. A display informs the user why the object is not accepted and if actions can be taken to make the object pass the scanner. For example, if more than one polymer is detected the user gets prompted to disassemble the object. Thus, the scanner ensures that no alien material enters the process. If an allowed material, for instance PET, is detected, the object is transported further to the sorting belt where gates guide it to the right bin. The user can follow the process visually and see how their waste finds its way to the right bin. In summary, this element offers things that the users and spectators do not see in their ordinary life (SEG 1.2). The interaction is straightforward and easy to use (SEG 1.8) and the spectators get insights in how sorting plastic can be done and the importance of that (SEG 2.3; 3.3).

Shredding - The Crane

In this element, which is called The Crane in the concept library, the plastic is shredded into small granules.

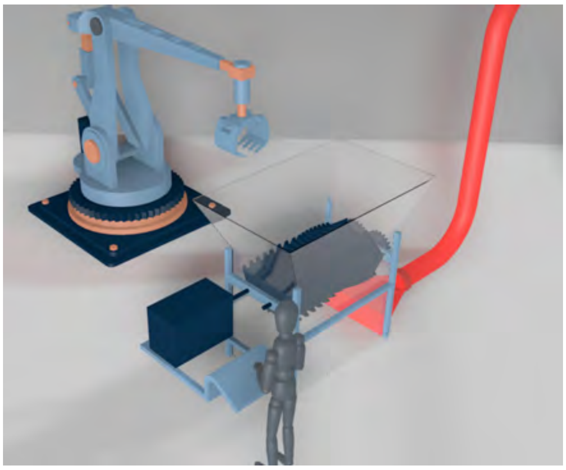


Figure 31. The shredding station in Plastfabriken 1.0

Element description

The sorted plastic from the Auto Scanner is loaded out of the bin into the shredder with a crane (see Figure 31) that is maneuvered by the user. The degrees of freedom in the movement of the crane is constricted so that no damage or hazardous situations occur. The shredder consists of several blades that rotate and granules the plastic waste. A mesh beneath the blades ensures that the plastic waste is disintegrated into pieces small enough to pass through the rest of the process.

User interaction

This element contains two POI. One for the crane and one for the shredder. Each POI is suitable for one user at a time. The crane is controlled via a joystick and can be moved freely but is limited so that the user cannot, purposely or accidentally, damage, hurt or destroy anything or anyone. For example, the limitations do not allow the user to turn the crane as long as its claws are in the bin, nor do they allow the user to lower the crane below the level of the bin except when it is exactly above the same. The shredder is controlled via two buttons, one for each direction. This allows the user to reverse the shredder in case the plastic should get stuck. This element attracts spectators to become users (SEG 1.15) through the possibility of steering the crane and through the visual experience of watching plastic waste get ripped apart by the blades of the shredder. The two POI support and encourage collaboration (SEG 1.7; 1.9). However, the maneuvering of the crane might be considered difficult by inexperienced users. Thus, further development to ensure that SEG 1.8 is considered enough must be made.

Washing - ManWash

The ManWash is a complement to the cleaning station in the beginning of the process. The plastic granules are washed here so that the dirt that could not be removed by the users in the cleaning element surely is eliminated.

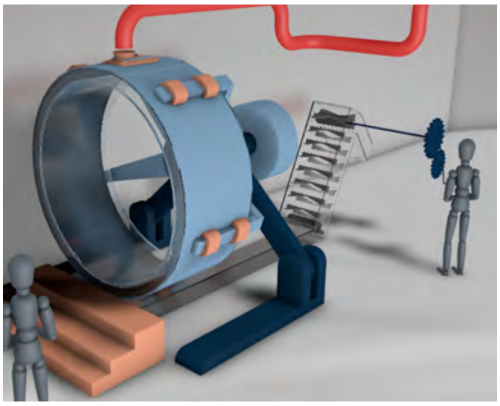


Figure 32. The washing station in Plastfabriken 1.0

Element description

The ManWash consists of a wheel that is attached to a centre axis via spokes on the backside of the wheel. The radius and dimensions of the wheel are customized so that an adult person can stand straight in it. The inside of the wheel makes up a water container (see Figure 32) into which the plastic granules are inserted via the input hach. Beneath the wheel is a water tank where the washed plastic is inserted for further treatment and transportation.

User interaction

In the ManWash the users are invited to use their physical strength to put the washing barrel in motion and wash the plastic. The inspiration for this element is from the treadwheel where human or animal strength and weight was converted to a rotation force.

Drying - Floor Sprinkler

The next step in the process is to dry the granules so that it can be melted properly in the manufacturing step. This is done by the Floor Sprinkler (see Figure 33).

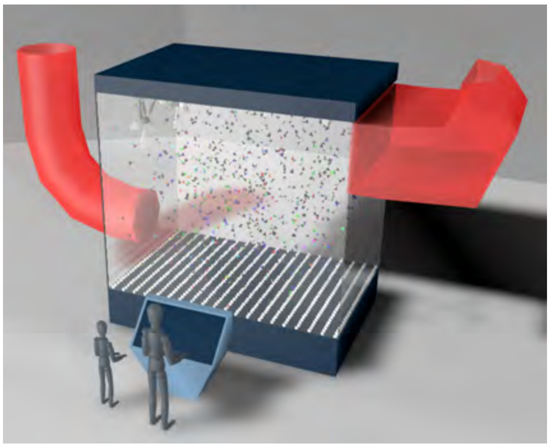


Figure 33. The Floor Sprinkler is drying the granules with hot air that is blown through nozzles that are controlled by the user.

Element description

This element, referred to as "Floor Sprinkler" in the concept library, utilizes hot compressed air to make sure that the plastic material is dry enough to be melted and molded into new things. It consists of a cuboid with acrylic translucent walls. The left side, seen from the front, includes the input tube which is attached to a hole in the wall. The hole is closed with a hatch when no plastic should enter the dryer. The opposite wall contains the output hole which also has a corresponding hatch that is closed unless the plastic is dry enough to leave the element. The floor of the cuboid is a fine mesh. Below the mesh a multitude of individually controllable air nozzles are arranged. Each nozzle has a LED light connected to it. The nozzles are controlled by users via a touch area placed right in front of the cuboid. The touch area is a representation of the floor of the cuboid and a touch on the touch area will activate the air nozzles on the respective floor area. For example, touching the upper right part of the touch area will activate the nozzles and connected LED lights in the far right corner. In such a way the users can play around making a plastic light show by dragging the hands over the screen. Further, the ceiling of the cuboid contains a quantity of lights that enhance the visual experience of the element. Three fans that are activated when the plastic is dry and when the output hatch is opened, are mounted on the left side of the ceiling. The fans ensure that the plastic material leaves the cuboid when it is dried.

User interaction

The Floor Sprinkler offers a POI that lets the users dry the plastic in a playful and creative way. The POI allows for more than one user at a time; rather, in certain situations, for example when the plastic should leave the element, it is indeed necessary to be as many as possible. Practically, the limits for how many users that can interact with the element is prescribed by how many hands that fit on the touch area at the same time. This feature means that the element both supports and encourages collaboration (SEG 1.7 and 1.9). However, the fact that the collaboration takes place on the same POI can cause undesirable interference between the users (Allen & Gutwill, 2004).

The Floor sprinkler is designed so that the exhibit visitors do not need to interact with it and still get a visual experience. When no users interact with the touch area, the element performs a pre-programmed show, utilizing the plastic granules and the light equipment, while drying the plastic. In this way, the element attracts visitors to become active spectators and eventually users, which corresponds to SEG 1.15 .

Gathering - Plastic Carousel and Spec Corner

Here the visitors are educated in the world of plastics during planned, supervised visits. In this element, the plastic material is stored pending the manufacturing element. The plastic material is ready for manufacturing when entering this element and no further treatment is made here.

Figure 34. The Plastic Carousel and the Spec Corner is a place where visitors can learn more about plastic material through workshops held by the staff at Universeum.

The Plastic Carousel (see Figure 34) is made to manage an overproduction of plastic granules, that is, if more granules are produced than what is used in the creating element. Furthermore, the gathering of granules enables the Spec Corner, which is the classroom of Plastfabriken 1.0.

Element description

The Plastic Carousel is completely automated and consists of six barrels, one for each plastic. Each barrel is attached to a ceiling mounted rig that is able to turn and is equipped with input and output hatches. The plastic material is transported to and from the gathering element in tubes. When a batch of ready-processed plastic material is about to enter the Plastic Carousel, the turnable rig automatically turns so that the right barrel is in the receiving position. For example, when a batch of PP plastic is on its way to the element, the turnable rig turns so that the barrel that stores PP is placed under the input tube. The PP barrel then opens its hatch and receives the plastic material. The same procedure is repeated when plastic material is to be released and delivered to the manufacturing element, except that this time the output hatch on the bottom of the barrel is opened. The plastic is then delivered to the manufacturing element via the output tube.

The Spec Corner is simply a viewing platform and furniture that supports simple experiments that can be of educational value for the visitors.

User interaction

The Plastic Carousel is automated and does not offer any user interactions. However, the visual appearance as well as the mechanical movement of the carousel will attract visitors to become active spectators since those are things that they do not see in their ordinary life, SEG 1.2..

The viewing platform is placed in close connection to the Plastic Carousel, so that users during certain hours can be offered a deeper understanding of plastics through workshops and lectures. The lecturer can in this corner present the different aspects of plastic and let the users feel and touch the plastic material. Furthermore, here is room for displaying the differences in plastic properties such as floating properties, hardness and tensile strength. This coincides with SEG 1.4, 2.3 as well as 3.3.

Creating - MegaMicroMolder

This element is designed to elicit wow-moments, not only through the fact that it melts the plastic granules and creates new things, but also through its appearance. This is considered necessary as the element does not offer any active user interactions.

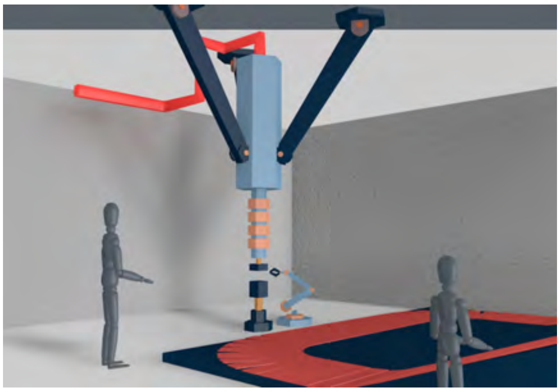


Figure 35. The MegaMicroMolder is an injection molding machine that is mounted in the ceiling in order to visually attract the visitors.

Element description

The MegaMicroMolder (see Figure 35), as this concept is labeled in the concept library, is regarding its functionality, an injection molding machine. However, it is rebuilt and disguised to a giant upside-down-rocket-like ceiling mounted artefact that draws attention from all of the exhibition. It is also the climax of the process since it is here the new thing is created. The MegaMicroMolder has its name from its giant "mega" appearance that converges down to a small "micro" mold wherein the creation happens. The main part of this concept is a hexagonal cylinder. On top of the cylinder, the input tube provides the machine with granules. Three legs are attached to the cylinder and mounted in the ceiling. From the main hexagonal cylinder, a smaller cylinder extends to the mold. The smaller cylinder is enclosed in heaters that melts the granules. The mold is divided in two where one half is attached to the smaller cylinder and the other is attached to a floor mounted device that is extendable so that the two mold halves can be merged when the melted plastic is injected as well as separated when the melted plastic is solidified in the mold

User interaction

This concept is to a large degree automated since the process is sensitive and must be conducted with great precision. However, the interface includes a LED light that turns green when the machine is ready for activation, while it is red when there is a process going on or if there are not enough plastic granules. When the LED turns green, the user can push the button and initialize the process.

This element scores high on the SEG that considers the visual appearance, for example SEG [1.14] and [3.4]. However, regarding SEG [1.1] and [1.5] scores low are since the process is closed and distanced from the users.

Delivering - Conveyor Pusher

This step is not necessary for the plastic recycling process but it ties together the exhibit and takes care of ejecting the new plastic item from the mold, which can be a riskful task since it would require the mold to be exposed to the users.

Figure 36. The Conveyor Pusher delivers the newly made plastic products. The users' task is to push the products off the conveyor belt, using the joysticks.

Element description

The element (see Figure 36) basically consists of a small industrial robot and a conveyor belt. The conveyor belt encapsulates an area where users can walk around while they observe the new items. In the upper part of the conveyor belt, six levers are placed. Each lever controls a piston that can push the items on the conveyor belt to a bench where they are displayed and where the users can take an item and bring it home.

User interaction

The user's task is in this element to push the newly made plastic items away from the conveyor belt so they end up on a displaying table. The user does that by pushing the lever that controls the pistons.

6. Phase three results

Due to feedback from stakeholders and a rejection from the potential funding agency, the project entered phase three instead of iterating and refining the results of phase two. Phase three consisted of a further development of Plastfabriken 1.0, making it more realizable and less costly to produce while still maintaining the requirement to be unmanned and meet the guidelines in the SEG-list. This chapter will provide the results from the user tests and the presentation of Plastfabriken 2.0.

6.1 Feasability makeover

After developing Plastfabriken 1.0 in a virtual reality space it was possible to let people experience and interact with the exhibit using a virtual reality system. During the midterm presentation this method was used to collect feedback from the employees at Boid. The key outtakes from the session were that Plastfabriken 1.0 had good potential of being an exciting and fun exhibit but that it, with this design, would be too costly. Furthermore, they also doubted the manufacturability of some of the elements. These concerns had a major impact on the further development of Plastfabriken and resulted in it undergoing a feasibility makeover. The feasibility makeover stated the start of the development of Plastfabriken 2.0. During the feasibility makeover the decision was made to instead of designing the elements to be modular and have the possibility to be placed wherever, they should be grouped together as *The Wall concept* from the Concept library. This not only meant that all elements underwent a redesign in order to achieve a smaller form factor but also that the conditions for the POIs changed drastically. Using the Interactions section from the Concept library proved to be an efficient way of coming up with new ideas and concepts for the POIs for the redesigned elements.

6.2 User tests results

From the user test, four categories of key findings could be extracted. These were: *design proposals, user actions, emotions* and *analyses*. The user test's main goal was to test the points of interactions (POI) and to validate their functions or to find opportunities for improvement. These so-called points of interactions are the actual locations where the user is given the possibility to engage with the exhibit and by engaging also change or affect the outcome. For example a crank that can be rotated by the user which moves or changes part of the exhibit, thus changing the outcome. Additionally, the overall experience of the exhibit was also examined. The participants were asked to express both their own thoughts as well as what they believed their kids would feel and think when going about interacting with the exhibition. Hence, all data gathered from the user test refers to both children and adults. The results are shown in tables in regards to the four categories and present the most valuable findings. The findings were both highlighting what the users thought were good design solutions, suggestions for improvements and general relevant reflections. The complete list can be found in the appendix (see appendix I)

6.2.1 Design proposals

In *Design proposals* are the findings from when the user expressed opinions or thoughts concerning the design of the elements, POIs or exhibit as a whole.

Table 17. The most valuable and interesting findings from the user test about the design of the exhibit

[i01]	Clean the bottle
[i01:03]	Illustrations showing the process of cleaning will increase the understanding of what the user is meant to do
[i01:05]	The wall around the hole for the caps makes it unpleasant to use
[i02]	Shredder
[i02:02]	Let the button have a shape that recurs in the shape of the shredder so that they more easily can be linked together
[i02:03]	Let the shredder rotate always and instead use only one button to reverse the rotation
[i03]	Crank
[i03:01]	Use a mirror that will enable one to see the top of the conveyor belt as well
[i04]	Cleaning
[i04:01]	There should be something where the user can put their feet to take take brace against themselves
[i04:03]	Let the pull strap be located at the back side instead to cover less of the machine
[i04:05]	The handle stopper should encroach less on the space where the user would want to put his or her hands
[i05]	Drying
[i05:01]	Emphasise more on the interaction or function where all granules is meant to be blown up the tube when the drying is finished
[i07]	Create
[i07:01]	The user should be able to see the molded part before it goes away to the shop

6.2.2 User action

User action focuses on defining what the user action is when presented to the POI, element and exhibit. And furthermore examine if any unintended behaviours are presented.

Table 18. The most valuable and interesting findings from the user test about the user action

[j01]	Clean the bottle
[j01:02]	The user will try to push, twist and turn on the washing station
[j01:04]	The user will try and use the washing station to splash water onto other users
[j02]	Shredder
[j02:02]	The user will collaborate with other users to try and shred as much plastic bottles as possible
[j03]	Crank
[j03:01]	If the motion is too physically demanding (much resistance) the user would interact less with it than if it had low resistance
[j03:02]	The user will want to try and get the granules to the end as quickly as possible by cranking the fastest possible
[j04]	Cleaning
[j04:04]	The user will try to figure out the interaction if it wouldn't have had any movement by itself, showing what was meant to be done
[j05]	Drying
[j05:02]	The user and a friend to the user will try to max out the blow in order to blow all granules out the pipe in the top
[j06]	Fish Stair
[j06:02]	The user will collaborate with another user to pull one handle each

6.2.3 Emotions

The *Emotions* category includes the test subject's sayings and expressions during user testing that can be related to specific emotions or a state of mind.

Table 19. The most valuable and interesting findings from the user test about the emotions of the user

[k01]	Clean the bottle
[k01:03]	The user might enjoy using a reverse vending machine
[k01:05]	The user will think the "clean the bottle" process is very fun
[k02]	Shredder
[k02:01]	The user will feel that destroying something is fun
[k02:02]	The user will feel that controlling the shredder would be fun
[k03]	Crank
[k03:02]	The user will feel satisfied by accomplishing to move the granules to the end of the conveyor belt
k[04]	Cleaning
[k04:01]	The user will not feel intimidated to try and pull the handle even if the handle stopper occupies some of the gripping area
[k04:04]	Things that spins are perceived as fun by the user
[k05]	Drying
[k05:01]	The user will enjoy discovering that the buttons cohere to a air nozzle and that each button activates one certain nozzle
[k05:02]	The user will not be intimidated to try the interaction
[k05:04]	The user will think it is to try and blow the granules out the top of the chamber
[k06]	Fish Stair
[k06:01]	This element will be fun for the user to interact with
[k06:02]	Using this element might raise a sense of challenge that will be fun
[k07]	Create
[k07:01]	The user will think it is fun to get something after completing the process
[k07:02]	The user will feel like it was thanks to he or she that the part was produced and proud over it
[k07:05]	The user will enjoy being able to see how plastic recycling works since it is something that is difficult to experience or see
[k07:06]	The user will think it was very exciting that a new part is created from recycled plastic bottles

6.2.4 Analyses

During the user testing on the 3D modeled Plastfabriken 2.0 with the parents, they often expressed analyzing thoughts regarding an element or POI. These were questioned and asked to be further clarified which then made it possible to extract these thoughts into key findings.

Table 20. The most valuable and interesting findings from the user test where analysing thoughts were expressed.

[l01]	Clean the bottle
[l01:01]	The user might be distracted by the washing station which might result in them not noticing the hole where the bottle is intended to enter
[l01:03]	Having a wall covering the rest of the process will make the users anxious to discover and see the rest of it which will make the users explore more of the exhibit and not just the Clean the bottle station
[l02]	Shredder
[l02:02]	The user would want to know what will happen before he or she tries it
[l03]	Crank
[l03:02]	The user would immediately understand what to do at this POI
[l03:03]	The user will not be careful with the equipment since it is placed at a science centre and here it is ok to be rough and try everything that is possible to try
[l04]	Cleaning
[l04:01]	For the interaction to function properly it requests that the user grabs the handle with both hands and pulls
[l05]	Drying
[l05:02]	The user will think this element is less challenging than the rest of them
[l05:03]	The user is not going to be attracted to compete at this element since it is not physically demanding
[l05:04]	The user will probably sense a feeling of game playing with trying to get the granules out the top tube
[l06]	Fish Stair
[l06:02]	It is a physical challenge for the user with a direct link to something visually which is a instant reward
[l06:03]	The element feels a bit tricky to understand and to conduct the interaction correctly
[l07]	Create
[l07:01]	The part is a direct connection to the recycling process so by having the part, the user will remember the process

[I07:04]	The user will probably remember most of the steps in the process
[I07:05]	Since the exhibit holds so many elements and POI, the user will probably only remember a few of them and not all

6.3 User test analysis

This section provides an analysis of the results from the user test.

6.3.1 Was the task understood?

Having the user test start with the participant being shown the exhibit and let to interact with it without being told what the main task of it was opened up for the possibility to, in the end, ask the user what he or she thought the exhibit was supposed to be. All test participants answered something in line with it being a plastic recycling machine. When asked if they thought their kid/child would also understand this, 3 out of 4 said yes. However, the one saying no answered that her kid would not think of it as a recycling process but would still remember the exhibit as where a plastic bottle was turned into a new product. Some participants expressed, in surprise, that they were fascinated that a plastic recycling process could look like this, still without being told it was one.

Regarding the POI, the overall impression was that the participants understood how to interact with the elements and what should be accomplished [k04:01, k05:01, l03:02] (see Table 19). However, some POI yielded uncertainties. For example, the first element (cleaning) was one of them. The participants were not sure what the task was and they did not recognize the specially made water tap and did not understand how it should be used. The participants expressed doubts whether their kids would dare to try to do things here, due to the lack of clues and instructions [i01:03] (see Table 17). Further, the buttons on the POI for the shredder evoked doubts regarding the functionality [i02] (see Table 17). The participants did not understand the connection between the buttons and the shredder.

6.3.2 Was the exhibit fun to interact with?

At first glance, when the participants were introduced to the exhibit, questions were asked regarding what part of the exhibit they think their child would want to approach first. Many said that everything looked fun and that it would be difficult to decide on one part to be more fun than the rest by only watching it. Expressed by a few however, were that the tall elements, such as the dryer and washer, looked a bit more fun than the rest. All elements got positive feedback in regards to the experience when engaging with them [k01:03, k01:03, k02:01, k03:02, k05:04, k06:01, k07:01] (see Table 19). The element that got the most positive feedback regarding how fun it was to interact with was the dryer. This could arguably be because it, even though it has a simple interaction, contains many segments and has a high level of accomplishment on multiple guidelines at once.

Some participants expressed concerns regarding the elements that are driven with muscle power as input. They were doubtful whether the users would have the strength and patience to accomplish the task that was connected to those elements [j03:01] (see Table 18). Still, the participants expressed that these types of interactions are fun. However, it is crucial that the mechanics are smooth and friction-free.

6.3.3 Did the users learn anything from the exhibit?

The participants were asked at the end of the user test if they had learned anything new after interacting and experiencing the exhibit. Only one of the participants answered yes but they all said that their children would definitely learn more about how plastic is recycled. Added by the majority of participants was also the fact that the users could keep the molded part in the end would help them remember the process.

6.3.4 Was the exhibit suitable for 11-year olds?

What the user test was most clear about was that 11-year olds and children around this age would love to interact and experience this exhibit. There was no doubt with any of the participants when this question was asked. All positive feedback regarding the experience of interacting with the exhibit further claims that it is very suitable for 11-year olds. Many even stated that they themselves and other adults would appreciate the exhibit. And even though the exhibit’s main target group is children, visiting science centres is considered to be a family activity where both adults and children learn, play and explore together. Hence, it is of importance that not only children appreciate the exhibit but also the adults.

6.3.5 Feedback from user test in further development

The feedback from the user test resulted in valuable insights for the further development of Plastfabriken 2.0. Two major changes were implemented as a direct consequence of the user test. The cleaning station was redesigned and also equipped with clear instructions. Furthermore, the buttons at the shredding POI were redesigned so that the functionality became clearer, using distinct symbols. Other aspects, such as the ones regarding the muscle powered elements and whether the users will have the strength and patience to properly maneuver them, are considered. However, these features (a crank and handle bars) were decided to be kept until thorough tests can be made with physical models, due to the positive feedback these features elicited.

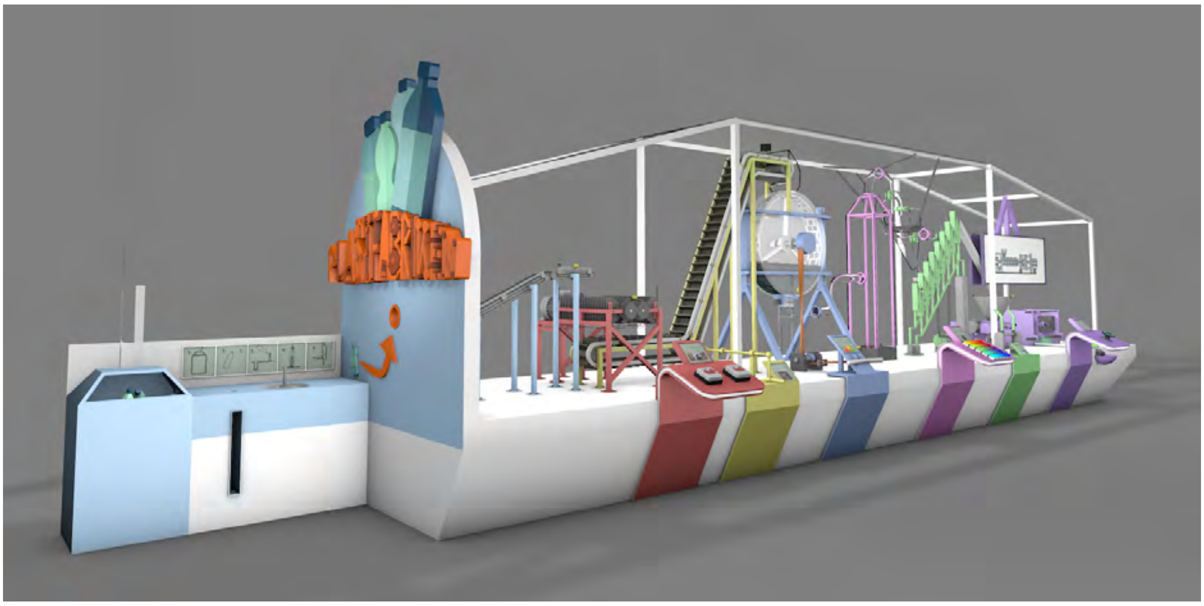


Figure 37. Overview of Plastfabriken 2.0.

6.4 Plastfabriken 2.0

Plastfabriken 2.0 (see Figure 37) is a recycling machine with seven POI, that produces new plastic parts from recycled PET bottles. It is designed to be the centrepiece of the plastic exhibition at Universeum. It has dealt with the problems encountered when developing Plastfabriken 1.0, especially regarding realizability and feasibility.

6.4.1 Bigger picture

The layout for Plastfabriken 2.0 is derived from the Bigger Picture that is called *The Wall* (1) in the Concept Library. Even though it is not mounted on a wall, Plastfabriken 2.0 contains the same features that *The Wall* presents. Moreover, mounted on a table, Plastfabriken 2.0 allows not only for the pedagogic flowchart layout, but also for more people to gather around it since it can be placed in the middle of the room. This also increases the potential for Plastfabriken 2.0 to be a conspicuous centrepiece of the exhibit. While all POI are placed on one side of the table, the process can be observed from all sides.

6.4.2 How to use Plastfabriken 2.0 in seven steps

This section guides the reader through the entire process using Plastfabriken 2.0. The process is presented in 8 steps. Each step contains a description of the respective element and how it is supposed to be used. Furthermore, a connection to the SEG-list (see Appendix IV) and a brief construction proposal is provided for each step.

Step 1 - Plastfabriken 2.0 Bins: Recycle the PET bottle

At the waste stations, inside the Universeum building, the visitors find the Plastfabriken 2.0 Bins. All Plastfabriken 2.0 Bins are equipped with a sensor, a microprocessor and an LED strip mounted to the wall that leads from the waste station to Plastfabriken 2.0. The LED strip pulsates light in the direction towards Plastfabriken 2.0. Thus, it functions as marketing and is supposed to attract visitors at Universeum to visit Plastfabriken 2.0. The bins are emptied by personnel, gathered and used to feed Plastfabriken 2.0.

Interaction

Plastfabriken 2.0 supports itself using the PET bottles that the visitors consume. Thus, the interaction with Plastfabriken 2.0 begins at the waste stations throughout the Universeum building. Visitors are invited to put their used PET bottle in the specific dedicated Plastfabriken 2.0 Bins at the available waste stations. When a bottle is thrown in a Plastfabriken 2.0 Bin, the sensor gives a signal to the microprocessor which in turn sends green pulses along the LED strip. This makes the visitor aware that their waste is used in Plastfabriken 2.0 to become new things.

SEG Implementation

This part of Plastfabriken 2.0 is an introduction which is designed to evoke curiosity and attract users to visit Plastfabriken 2.0. Therefore, it does not necessarily provide the user with extraordinary experiences and aha-moments. However, it highlights that waste separation is important by the special treatment of the bottle, which corresponds to SEG [3.3].

Construction proposals

The LED strip along with the sensor can be controlled by for example an Arduino (Arduino, 2019). The use of Arduinos is already widespread within the science centre culture.

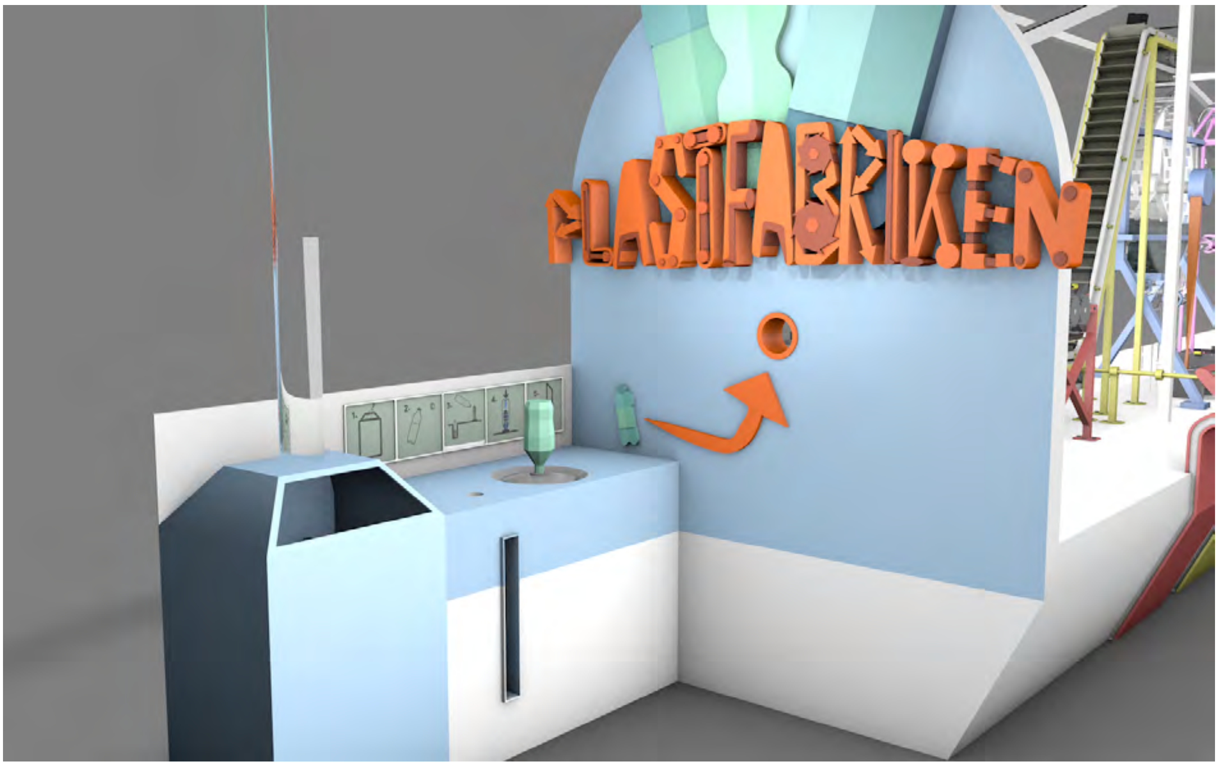


Figure 38. When a PET-bottle has been thrown into the specific dedicated Plastfabriken 2.0 Bins, the pulsating LED-strip will lead the visitors to Plastfabriken 2.0 and this first element of it - the cleaning station.

Step 2: Remove the cap and clean the bottle

This step consists of a bin and an altered kitchen sink (see Figure 38). The bin and the sink are attached to each other. The bottles collected from the specific dedicated Plastfabriken 2.0 Bins, located at different locations in Universeum, will be placed in this bin for the users to take when interacting with the exhibit. The sink consists of a special made water tap and a container for the screw caps. The separation of the screw caps is necessary since they are made of another plastic (HDPE typically) than the bottle, and Plastfabriken 2.0 only accepts PET.

Interaction

In this step, the user takes a PET bottle from the bin at Plastfabriken 2.0. Then the user separates the cap from the bottle and puts it in the container for caps. To clean the bottle, the user uses the dedicated bottle cleaner. It is designed to only be activated with a bottle. The actuation is made by firmly pressing the bottle over a special made water tap. When pressed down, the water stream starts and rinses the inside of the bottle. Lifting the bottle of the tap will let all water pour out into the sink. In this way, the risk of water fights is decreased. After this, the user puts the bottle in the hole in the wall and pushes the button to initialize the conveyor belt to start.

SEG Implementation

This step answers well to SEG [1.5], since the users are supposed to grab the bottle by themselves and clean it. Unfortunately, this step is the only one in the process that reaches this level on SEG [1.5] (which can be seen on the ES-scoring in 7.1.6), since the rest of the process is enclosed in plexiglass due to the small plastic flakes that otherwise would have been all over the exhibit. SEG [1.1] is arguably fulfilled as well as SEG [1.11] because of this step's total dependency to the users' actions. The special made water tap might lower the scoring on SEG [3.1], since it functions in a way that the users are not used to.

Construction proposals

This step consists of things that cannot be found on the market, as it is currently designed. The special made water tap could be replaced with an ordinary tap but with the risk of encouraging water fights. The action of activating waterflow by applying force to specific parts is however similar to the system used in garden hoses. Same goes for the bin with the bottles. There are no certain requirements for the bin, more than the size and height are of importance to make sure it is suitable for the application. From testing it has been found that a height of no more than 95 centimeters and less than 75 is desirable.

Figure 39. The Super Hero Shred consists of the POI panel with two buttons and a screen and shredder.

Step 3, Super Hero Shred: Shred the bottle to granules

The Super Hero Shred (see Figure 39) consists of a conveyor belt, a shredder and a POI panel. The PET bottle arrives via the conveyor belt to the shredder and waits for user input. The shredder consists of two mirrored axes whereon several blades are mounted. When the blades are turned, the bottle gets torn apart into smaller pieces (see Figure 40).

Below the blades is a mesh filter mounted so that only granules that are small enough are let through. The right size is determined by the injection molding machine at the last step in Plastfabriken 2.0. The proposed machine requires a granules size of maximum 4 by 4 mm ("Digg desktop injection molding machine" 2019). If the granules are too big to pass the mesh, the blades catch them again and tear them to a smaller size until they are small

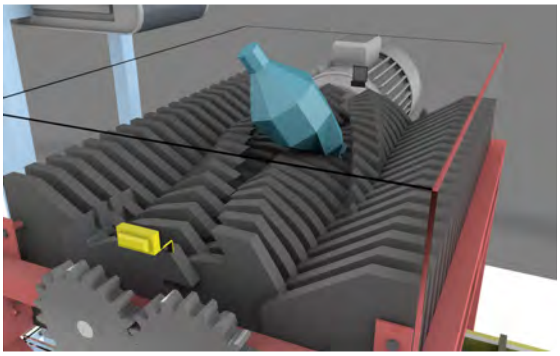


Figure 40. The blades of the shredder grabbing a PET bottle and shredding it into smaller pieces (granules).

enough to pass the mesh. When the granules pass the mesh, it falls down on the second conveyor belt, ready to be transported further.

Figure 41. The interaction point of the shredder offers the user to control the blade's rotation using two buttons.

Interaction

The shredder is controlled via a two-button interface where the user can drive the shredder forwards or backwards (see Figure 41). If the shredder is driven forward, the bottle is shredded. If the bottle for some reason gets stuck or if the shredder does not get a grip on the bottle, the user can reverse the blades of the shredder and then forward them again to make sure that the bottle gets shredded correctly. Furthermore, this lets the user have full control of the action. From the user tests it was found that letting the users have this much control over such a seemingly dangerous machine would really engage and captivate the user. The users expressed a lot of thrills and fascination about the interaction with this element and the power one controls when engaging with it.

SEG implementation

The Super Hero Shred lets the user be in control of the process (SEG [1.1]) and is something that is not seen in most user's ordinary life (SEG [1.2]). Moreover, the user tests showed that shredding plastic like that elicits wow-moments (SEG [1.14]) as well as being enjoyable at the same time as the user learns about the plastic process (SEG [2.4]).

Construction proposals

The Super Hero Shred can to large extent be built from off the shelf products. Conveyor belts suitable for this application are sold for around 10000 SEK ("PVC conveyor belt" 2019). Regarding the shredder, it might be a good solution to build one. Most "off the shelf shredders" are not suitable for science centres due to rigid closed steel sheet casing which is needed in high capacity industrial lines. However, in a science centre, it is desirable, from an educational perspective, to make the process as transparent as possible. Thus, the best way to go might be to utilize the shredder blueprints provided by Precious Plastics. Then find inspiration from the Perpetual Plastic Project as they have shredders (although smaller in size than what is suggested in Plastfabriken 2.0) where the housing is made in plexiglass.

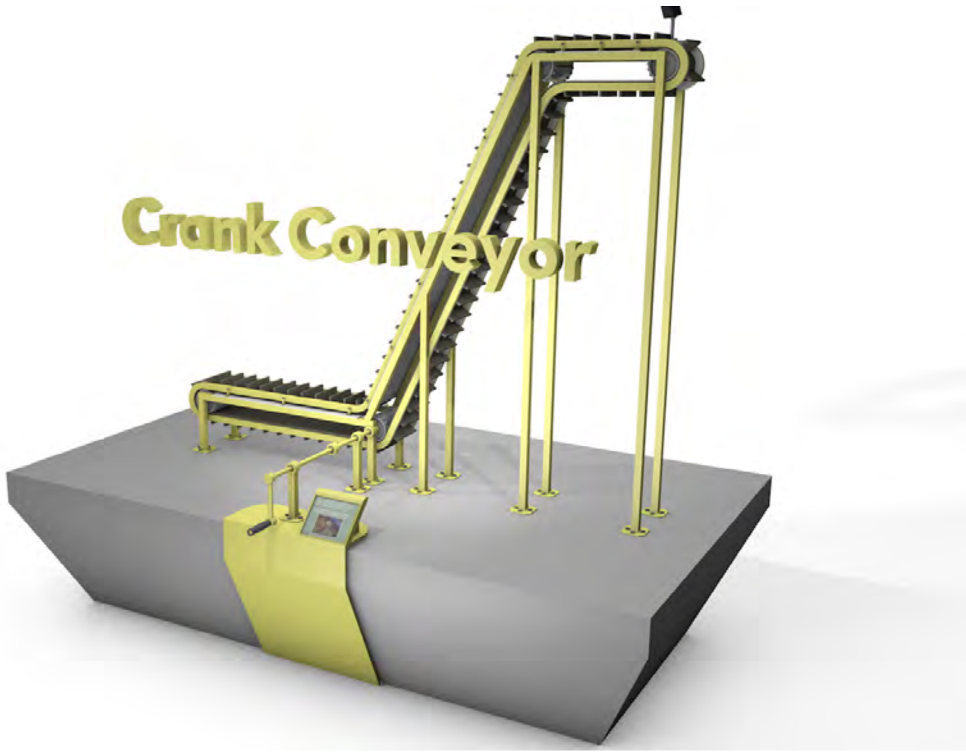


Figure 42. The Crank Conveyor which lets the users move the plastic forward in the process by rotating the crankhandle.

Step 4, Crank Conveyor: Transport the granules

A conveyor belt transports the granules from the shredder to the next element. The conveyor belt is completely covered with plexiglass to prevent granules from falling off it. The belt is equipped with ribs that hinders the granules from falling down during the steep incline.

Figure 43. The crank handle and screen with live broadcasted images from camera on top of the conveyor belt.

Interaction

The Crank Conveyor (see Figure 43) is controlled by the user via a crank. When the crank is turned, the conveyor belt rolls and the granules are transported up to the next element - the washer. The crank and conveyor belt can only be turned in one direction, to make sure that the granules are transported upwards. Because of its height it is impossible to see the granules at the top of the Crank Conveyor. To solve this problem, there is a camera mounted on the top of the frame that broadcasts a live picture to the screen at the POI panel.

Seg implementation

Since the users are in control of the crank, SEG 1.1 is fulfilled. Also, SEG 1.6 is considered since it is the user's muscle power that drives the conveyor belt. However, the fact that the element relies on the user's physical power raised some concerns during the user tests, as the participants doubted that eleven-year-olds have the patience. That is valuable insights that should be considered in further development. However, also from the user tests it was found that this element could introduce an event of competitiveness where the users could try and transport the granules as fast as possible. This was said to be a positive thing that could encourage the user to interact and contribute to collaboration as well.

Construction proposals

In order to create a Crank Conveyor, the construction of the conveyor belt must be custom made to fit the size requirements. However, the crank conveyor could be replaced with essentially anything that lifts the plastic up to the Washing Drum in the next step. There are a lot of conveyor belts on the market and with smaller modifications, many could work.

Figure 44. The Washing Drum. This element's main task is to clean the plastic granules from residues and impurities.

Step 5, Washing Drum: Wash the granules

In this step, the granules get washed so that dirt and residues dissolve with the help of detergents in the water.

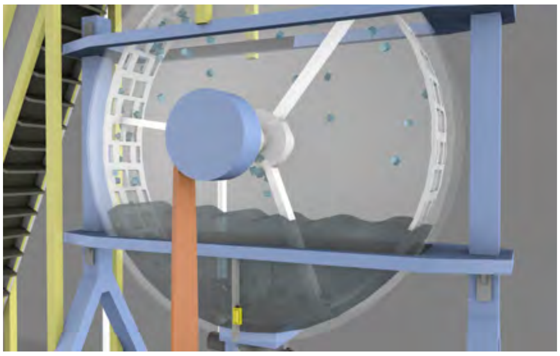


Figure 45. Close up on the water tank, drum and granules being swirled around due to rotation of the drum. Also visible are the yellow sensors that send a signal to the brain of the system when enough granules have entered the tank.

The Washing Drum (see Figure 44) consists of a translucent acrylic water tank with an input hatch at the top and an output hatch at the bottom. As tests (see 3.3.3) showed that lights improved the visibility of the granules in water, the water tank is equipped with LED lights that light up the granules in the water. A drum that resembles the one found in washing machines is mounted in the middle of the water tank. The drum consists of a perforated cylinder that is supported by three spokes which in turn is attached to a centre axis (see Figure 45). It is the rotating drum that causes turbulence in the water so that the plastic granules get washed and cleansed. The drum is completely manual and driven by the users. However, parts of the process are automated. After the water tank is emptied, the Washing Drum awaits new plastic granules to enter the tank. In this state, the input hatch is open while the output hatch is closed. A sensor tells the input hatch to close when a batch of granules has entered the water tank. Then, the tank gets half filled with water. The user is invited to start driving the drum. A sensor controls how many revolutions the drum has made and after a specific amount of revolutions, the granules are considered clean and the output process starts. The output hatch is then opened and the granules along with the water is poured out. A filter is placed below the output hatch so that the water goes down into the internal water system that cleans the water and makes it ready for the next batch of granules. The granules stay on the filter and are transported further by compressed air via a tube to the drying element, the Floor Sprinkler.

Figure 46. The Point of interaction of the Washing Drum offers a handle attached to a belt that when pulled rotates the drum inside the tank.

Interaction

The drum is driven by the user in the same way that a rowing machine is driven. The interface is also the same found in the rowing machine. A handle that the user is supposed to pull is attached to a strap (see Figure 46). The strap in turn runs, via a supporting wheel, to a trundle that is attached to the axis that holds the drum. The user can use the machine at any time, even when the water tank is empty and when the tank gets filled up. The handle always springs back to default position in the handle stopper. From the user test, this interaction was found to be easy to understand. This is because the recognition of the handle invites the user to try and pull it. Even though the result of pulling the handle is not clear beforehand, it will quickly become so after the first pull and the user sees the drum rotating as a result. This element's strength was found from the user test to be the direct correlation between input and output. When the handle is pulled faster - immediate results can be seen as when the water gets a stronger turbulence. The Washing Drum will be visually intriguing to watch since it puts large objects into motion. The drum will rotate and a large amount of water with granules will swirl around. This was found from the user test to exceed the initial expectations of the element and thus increase the quality of the experience [2.7].

SEG implementation

The participants in the user test expressed that the appearance of the Water Drum is intriguing and attractive. Thus, it corresponds to SEG [3.4]. Also, the Water Drum is made with SEG [1.1] and [1.2] in mind. [1.1] since the users are in control of the process, and [1.2] since the user gets to see how a washing machine works and looks on the inside. SEG [3.3] is arguably answered as the user understands the importance of washing the plastic in this step. Furthermore, it fulfills SEG [1.6] since the element is driven by muscle power. However, the same concerns as for the Crank Conveyor appeared on the user tests. Thus, that must be considered when further developing the Washing Drum.

Construction proposals

The mechanical principles of the Water Drum is similar to how the rowing machine WaterRower functions (Waterrower, 2019). The transmission from the handle to the object that spins in the water tank is the same, even though the layout is different. Thus, one option is to purchase a WaterRower (costs from 10000 SEK (WaterRower A1: Home rower, 2019), and use the relevant parts.

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Figure 47. The Floor Sprinkler.

Step 6, Floor Sprinkler: Dry the granules

The Floor Sprinkler (see Figure 47) is in many ways similar to the corresponding element in Plastfabriken 1.0. However, this version is condensed and simplified to meet the new demands in phase three of the project. In the same way as its predecessor, this Floor Sprinkler consists to a large degree of a plexiglass cuboid. The top of the cuboid is narrowed down like a pyramid and at the very top an output tube is attached. The bottom of the cuboid contains air nozzles, just like in Plastfabriken 1.0. However, in this version they are fewer, 25 (5x5) to be exact, and not as closely packed. In close connection to each nozzle, a LED light is arranged to light up every time the air nozzle is activated.

The air that is blown into the cuboid is hot and dry, which leads to a fast drying process. A sensor that measures the moisture of the air that flows out of the cuboid tells the system when the granules are dry enough to be melted and molded. When it is, the output hatch in the top is opened and all nozzles blow full power so that the granules are forced to leave the cuboid and travel through the output tube and into the funnel that leads it to the next element.

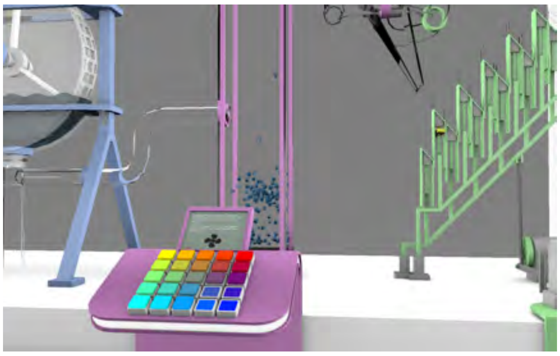

Figure 48 .When the buttons are being pressed down at the Point of Interaction at the Floor Sprinkler, the granules will shoot up in the air.

Interaction

Each air nozzle in the cuboid is controlled by a button on the user interface. Each button in turn is placed on the interface in a way so that the placement corresponds to the placement of the respective nozzle. Thus, if the user pushes the upper right button, the far right nozzle in the cuboid, and its respective LED light is activated. The LED lights give the user feedback on how the interaction works. Furthermore, they let the user be creative and perform a lightshow as they dry the granules. From the proof of concept testing (4.3.3) it was found that blowing the granules up in the air using high pressure air created an intriguing and captivating effect that was both fun to control but also to look at. This was further confirmed in the user tests.

SEG implementation

The way Floor Sprinkler lets the user play with lights and blow granules into the air makes it fulfill both SEG [1.14] and [3.4]. Moreover, SEG [2.4] and [2.5] correspond to these features. Due to the fact that the granules are only allowed to leave the element when it is dry enough, the user understands that the plastic must be dry enough in the process. Thus, SEG [3.3] is also considered.

Construction proposals

As the Floor Sprinkler is currently designed, it demands custom made parts. However, it could be simplified to only have one air nozzle, but not without compromising the user interactivity and experience.

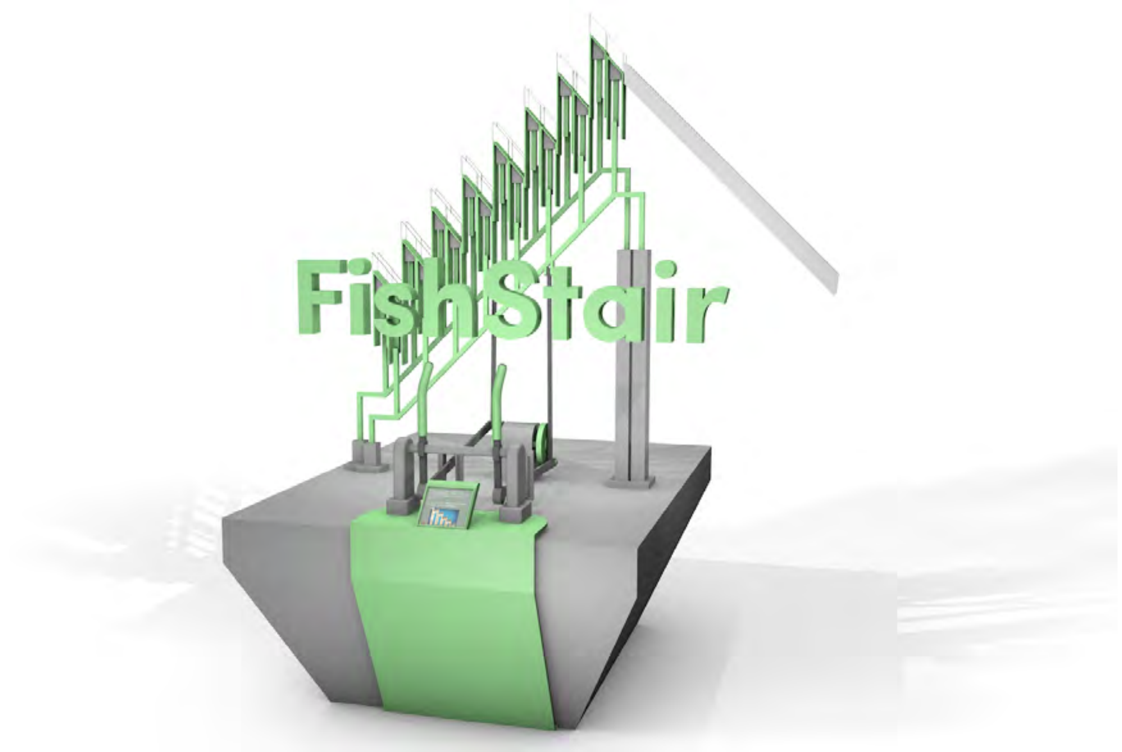

Figure 49. The Fishstrair.

Step 7, FishStair: transport the granules

This step lets the user play with and understand the principles behind the fishstair mechanism.

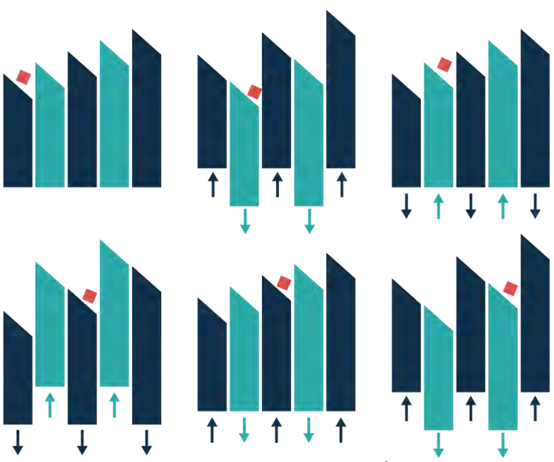

Figure 50. The principle of how the granules will move upwards in the FishStrair.

The principle is shown in Figure 50. The fishstair consists of five steps. In this example, the square is to be transported up to the fifth step. In 1) the steps are in default position and the square rests on the first step. In 2), step one, three and five are elevated while step two and four are lowered. In this position, the square is able to slide down to the second step. In 3) and 4), the movement is the opposite where step two and four are elevated while one, three and five are lowered. Repeating this process will cause the square to move upward and forward.

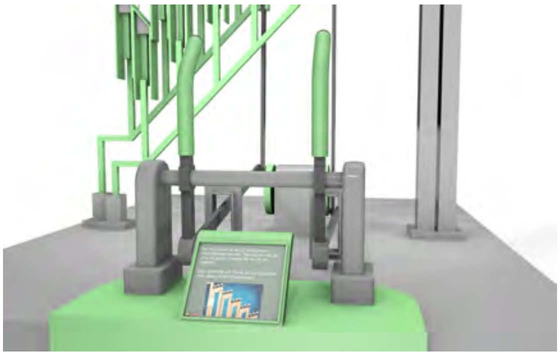

Figure 51. The handles and the screen of the FishStair. Moving the handles back and forth will move the steps up and down. .

Interaction

The fishstair is driven by user force input. The interface consists of two levers that can be put back and forth (see Figure 51). The construction resembles the one found in cross trainers.

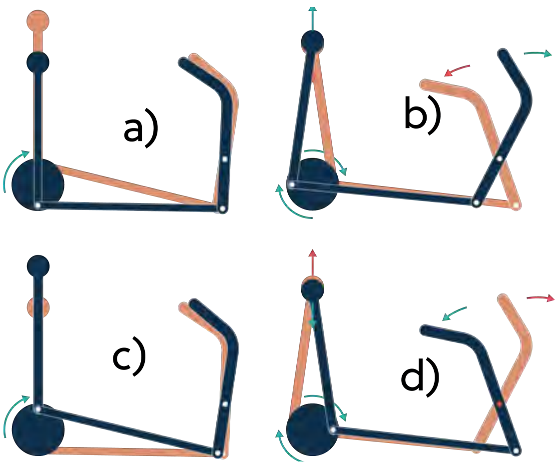

Figure 52. The handles are pushed back and forth, making the wheel spin and making the stairs move up and down.

Figure 52 shows how the transmission works. There are two identical sets of the handles and transmission rods, each connected to one set of stairs in the fishstair. However, the movement of the second lever is offsetted two steps. Thus, when one of the levers is on position a), the other one is on position c). The user input is with this mechanism translated to a vertical movement. The offset between the two levers creates a movement that makes it possible for the two sets of stairs to be in the positions illustrated in figure 50.

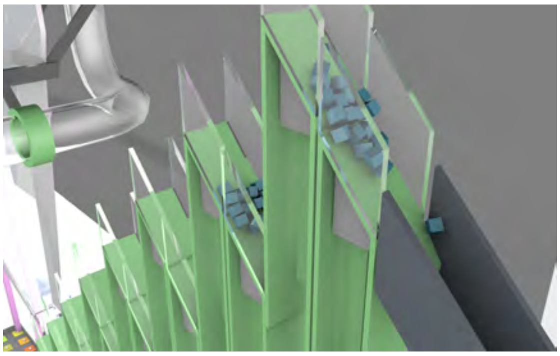

Figure 53. When the granules reach the top of the stairs it will fall down into the hopper of the Injektor via the slide.

SEG implementation

Letting the users play with and discover mechanical constructions increases the chances for aha-moments SEG [2.3], even if it is not a necessary part of the plastic recycling process. The design of the user interface allows for collaboration SEG [1.7], however, the Fishstair can be managed by one user as well. As for the other elements where the user's physical strength is used to run the machines (Crank Conveyor and Washing Drum), the FishStair also fulfills SEG 1.6. In the same way, the participants showed the same concerns over whether the users will have patience and strength enough to run the Fishstair. This puts high demand for smoothness in the mechanism for this element.

Construction proposals

The current design of The Fishstair is not available off-the-shelf on the market. If the budget is too tight, this step can be discarded as it is not a part of the plastic recycling process. However, that is not recommended since the Fishstair contributes with both visual excitement, interactivity and mechanical ingenuity that affects Plastfabriken 2.0 as a whole in a positive way.

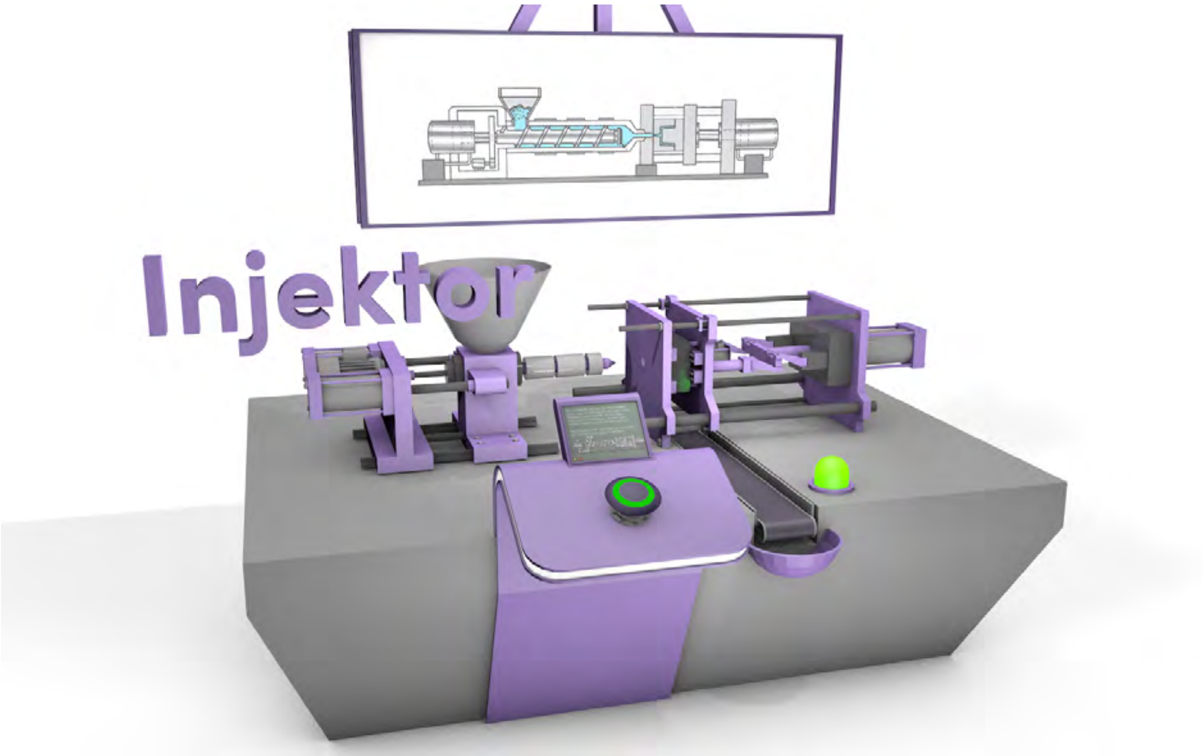

Figure 54. The final element in Plastfabriken 2.0, the Injektor.

Step 8, Injektor: Make something new with the granules

This is arguably the climax of Plastfabriken 2.0. This is the purpose of all the previous steps in the chain of elements. In this fully automated injection molding machine, new things are made from the granules that have formerly been a bottle.

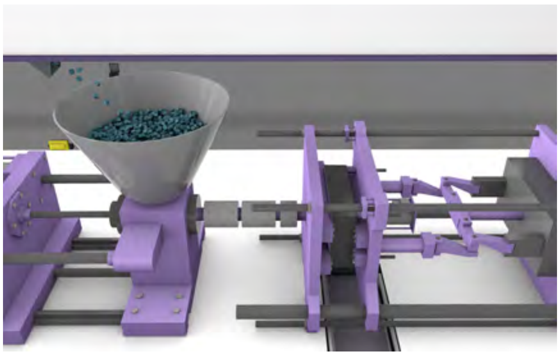

Figure 55. Closeup on the Injektor. From the hopper, the granules will enter the extrusion pipe and start melting from the heat from the heating elements.

The injection molding machine (see Figure 54) receives the granules from the fishstair, via a funnel to a hopper (see Figure 55). Upon actuation, the machine takes enough granules for the current mold from the hopper. The melting process takes place within a cylinder that is enveloped in heaters, while a screw within that same cylinder pushes the melted granules forward. The screw puts high pressure on the melted granules which makes it fill the mold. The pressure is kept until the plastic has solidified and then it is automatically ejected from the mold. Now, the machine is ready to do the procedure again.

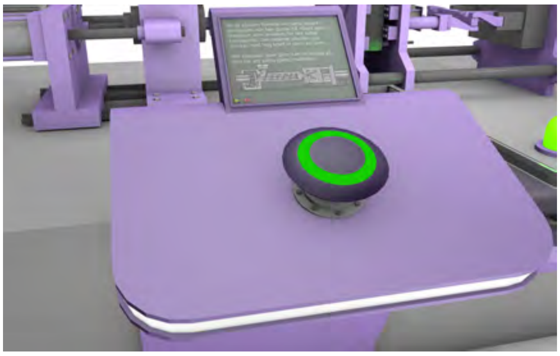

Figure 56. When the Injektor is ready to mold a new part, the button will light up green.

Interaction

This step in the process is as stated earlier automated since it is a complex task that puts high demand on all sub steps. However, since the context is a science centre, and since this is the final step where the users are rewarded for their work in earlier steps, the users are invited to initialize the injection molding machine. The interface is simple and consists of an LED and a button. When the LED turns green, the user can push the button and start the Injektor (see Figure 56). The LED then turns red and the button is disabled until the Injekton is ready for a new batch of granules. Also, if there are not enough granules in the hopper the LED is shining red and the button is disabled.

In order to increase the educational aspect of this step and to support the user's understanding of what is happening inside the injection molding machine, the Injektor is equipped with a screen. On the screen the process is illustrated in real time, as if the injection molding machine was exposed to x-rays.

SEG implementation

This creation part is not what most users see in their ordinary life. Thus, this element lives up to SEG 1.2. As this is the final step in Plastfabriken 2.0 and also the climax in the recycling process, the users will be enlightened and understand the importance of recycling; SEG [3.3]. The informative "x-ray" screen also increases the possibility for children to learn how the melting and molding process works.

Construction proposals

There are available injection molding machines on the market that could be suitable for Plastfabriken 2.0. The "Digg desktop injection molding machine" is manufactured by Robot Digg and costs 77414 SEK ("Digg desktop injection molding machine" 2019). It is a very affordable machine that has all the necessary features needed for the application. It has fully or semi automatic cycles and is capable of molding PET. It can mold pieces with the dimension wanted for Plastfabriken 2.0. It only needs to be modified to be able to be started by the user from the POI's switch.

6.4.3 Plastfabriken 2.0 ES-score

Plastfabriken 2.0 can only be partially evaluated using the ES-method. This is because the categories based on quantitative data collection can not be measured. However, based on the created 3D-model of the exhibit and data from the user test, the four ES-categories based on the SEG can be completed.

Table 21. Plastfabriken's *Design Features* score in the ES-method.

[1.0]	**DESIGN FEATURES (5,5)**	Level of acc-omplishment	Guideline weight	Score (330)
[1.1]	The user should be able to do stuff by themselves	4	9,5	28,5
[1.2]	The exhibit should contain things that users doesn't see in their ordinary life	5	7	14
[1.3]	The exhibit should involve as many parameters (senses) as possible	2	2,5	12,5
[1.4]	The exhibit should contain hands-on experiences	3	6	18
[1.5]	The visitors should be allowed and encouraged to touch and feel things	2	7,5	15
[1.6]	Utilize the muscle power of the visitors and use them as power input	5	6	24
[1.7]	The exhibit should encourage collaboration, between the users and their significant others	4	3,5	3,5
[1.8]	The interaction should be easy to use	5	7	35
[1.9]	The exhibit should effectively support collaboration	2	3	0
[1.10]	The exhibit should be designed to minimize the need for signs with extensive text chunks	4	3,5	10,5
[1.11]	The exhibit should effectively support interaction.	5	10,5	21
[1.12]	The interactive stations should reset to default position independent of the visitors	5	0	0
				182

Table 22. Plastfabriken's *Desired User Experience* score in the ES-method.

[2.0]	**DESIRED USER EXPERIENCE (4,5)**	Level of acc-omplishment	Guideline weight	Score (50)
[2.1]	The exhibit should consist of storytelling and narrative creation	5	0,5	2,5
[2.2]	The exhibit should elicit laughter	4	1	4
[2.3]	The exhibit should generate aha-moments	5	3,5	17,5
[2.4]	Children should find the learning experience enjoyable	4	3	12
[2.5]	The exhibition should utilize and encourage the creativity and imagination of the visitors	4	2	8

Table 23. Plastfabriken's *User Engagement* score in the ES-method.

[3.0]	**USER ENGAGEMENT (3,5)**	Level of acc-omplishment	Guideline weight	Score (15)
[3.1]	The exhibit should be self explanatory	4	1	4
[3.2]	Children should be actively interpreting material culture for themselves	3	0,5	1,5
[3.3]	Children should learn from the exhibit	5	1,5	7,5

Table 24. Plastfabriken's *Things To Avoid* score in the ES-method.

[4.0]	THINGS TO AVOID (1)	Level of acc-omplishment	Guideline weight	Score (180)
[4.1]	The design of the exhibition should not resemble inappropriate things (eg fallo)	4	1,5	6
[4.2]	Avoid nooks where visitors can hide things	5	1	5
[4.3]	The exhibit should not include loose theft-prone objects	5	4	20
[4.4]	The exhibit should not include loose objects	3	2	6

[4.5]	The amount of needed staff supervision should be kept at minimum	5	6,5	32,5
[4.6]	If signs are necessary, they should not score higher than 30 according to LIX	4	5	20
[4.7]	Avoid passive and voiceless material interpreting	4	4,5	18
[4.8]	The exhibit should not be perceived as frightening	3	4	12
[4.9]	The exhibit should be easy to understand	4	7,5	30

Table 25. Plastfabriken's score in the ES-method if full score is reached on *gender diversity, even POI attractiveness and level of engagement*.

	Score	Max score	Avg	Weight	IES	Max	%
Gender diversity	-	-	10	2	20	20	1
Even POI attractiveness	-	-	10	2	20	20	1
Level of engagement	-	-	10	2,5	25	25	1
USERS	-	-	-	-	65	65	1
DESIGN FEATURES	262,5	330	8	5,5	44	55	0,8
DESIRED USER EXPERIENCE	44	50	8,8	4,5	39,6	45	0,88
USER ENGAGEMENT	13	15	8,7	3,5	30,5	35	0,87
THINGS TO AVOID	149,5	180	8,3	1	8,3	10	0,83
					187,4	210	0,89

If, for example, the first three categories would score full, then Plastfabriken 2.0 would have an ES-value of 0.89 which is equivalent to an exhibit "extremely successful" according to the successful level scale. Realistically however, this scenario is unreachable. A realistic estimation would be to have an average of the first three categories comparable to the average of the last four. This is because the level of how well the SEG are accomplished should, in an ideal situation where the SEG are as accurate as possible, be reflected in the scoring of gender diversity, even POI attractiveness and the level of engagement. With this analysis as a basis, a more accurate ES-value of Plastfabriken 2.0 would be 0,84, as can be seen in the chart below (see table 26). According to the ES-method this means that Plastfabriken 2.0 has a score that is slightly better than a "very successful" exhibit.

Table 26. Plastfabriken's score in the ES-method if not full score is reached on *gender diversity, even POI attractiveness and level of engagement*.

	Score	Max score	Avg	Weight	IES	Max	%
Gender diversity	-	-	8	2	16	20	0,8
Even POI attractiveness	-	-	8,3	2	16,6	20	0,83
Level of engagement	-	-	8,3	2,5	20,75	25	0,83
USERS	-	-	-	-	53,35	65	0,82
DESIGN FEATURES	262,5	330	8	5,5	44	55	0,8
DESIRED USER EXPERIENCE	44	50	8,8	4,5	39,6	45	0,88
USER ENGAGEMENT	13	15	8,7	3,5	30,5	35	0,87
THINGS TO AVOID	149,5	180	8,3	1	8,3	10	0,83
					175,7	210	0,84

7. Discussion

This chapter considers insights and thoughts on the complete project. The discussion includes the project's final outcome but also the process leading to this result. The discussion is concluded with recommendations of further work.

7.1 Final results

This study resulted in three main products. The first are the Successful Exhibit Guidelines. These guidelines can be used during exhibit design to ensure the exhibit has high quality and increase the chances of it being successful. The second product is the Exhibit Scoring-method which can be used as a tool to analyse an exhibit and facilitate the work of improving it by pointing out weaknesses. The third product is Plastfabriken 2.0 which is the exhibit that is meant to be used as the centrepiece in the exhibition about plastics at Universeum. It is designed to change people's view of the value of plastic to be more valuable and thus induce a behaviour that has a more sustainable approach.

7.1.1 Will Plastfabriken 2.0 change people's view of the value of plastic?

This project's goal was to design a science centre exhibit that could recycle plastic in a way that could be compared to how plastic is recycled industrially. The exhibit should clearly be able to communicate what it takes in order to recycle plastics and by doing so, give the user insight and knowledge about the process. Furthermore, the goal of the design was to make the users reevaluate their usage of and attitude to plastic by changing their view of its value. Since the design results have been developed and presented only as computational models, defining whether or not the project is successful in reaching these goals, is somewhat problematic. However, Plastfabriken 2.0 is developed based on design guidelines (SEG-list) gathered from rigid and carefully conducted literature studies and observations. Therefore, it can be considered to be a believable and educational plastic recycling process. Additionally, the user test showed promising indications of its opportunities to educate the users. This is because all participants claimed that their children would learn more about how plastic is recycled after having experienced the exhibit. But the main reason for Plastfabriken 2.0 to be educative is to evoke a change in behaviour towards a more sustainable attitude to plastic and to do so by changing the user's view of the value of plastic. Even though it proves to be educational, it does not automatically mean that it will change people's view. But it is believed that this will be accomplished by the way the exhibit is designed. Having the first part (cleaning) look like a reverse vending machine (confirmed from the user test) will make the user connect this action to the already known action of recycling old cans and bottles. When the user in the end is rewarded with a new plastic product that can bring joy or fulfill a purpose, for example a phone cover, the user will think of how the plastic bottle in the beginning has turned into something more valuable only by being processed in Plastfabriken 2.0. By adding this value to the plastic material, the users will become aware of the possibilities of the material and value it more.

By comparing the project to other projects with the goal of turning plastic waste into new things, such as the Precious Plastic Project and the Perpetual Plastic Project, it can be determined whether or not Plastfabriken 2.0 is a believable plastic recycling process or not. It is clear that all three projects have distinct similarities. All three use thrown away plastic waste which, through processing, is molded into new shapes with different properties. This supports the supposition that the exhibit will be interpreted as a plastic recycling process by the user. The Precious Plastic project consists of a two step process; *shredding* and *creating,* but it could be considered to include *cleaning* and *drying* as well since it only processes clean and dry plastic. The Perpetual Plastic consists of a four step process; *cleaning, drying, shredding* and *creating,* and the Plastfabriken consists of a five step process; *cleaning, shredding, washing, drying* and *creating*. All the projects could be considered to have a process consisting of the exact same steps. The only two differences being that Plastfabriken 2.0 shows an even more detailed representation of how the industrial plastic recycling process works by showcasing more of the steps that are found in industrial recycling. And it has a design that is more comparable to what industrial processes look like. Plastfabriken 2.0 is thereby considered to successfully achieve with convincing the user that it is a believable plastic recycling process.

7.1.2. Will Plastfabriken 2.0 succeed with creating new parts from recycled PET bottles?

Within the project's goal was also to produce new objects from recycled plastics. To prove whether or not the exhibit will in fact be able to produce new objects from the collected PET bottles before it is built and properly tested, an analysis of the design results is needed.

Cleaning

The first step of the process is the initial cleaning. This is a crucial step in the process since too much impurities might cause problems in the later stages. Plastfabriken 2.0 ensures that the plastic is clean enough in three ways. Firstly, by only processing specifically PET bottles. Secondly, by having two seperate elements where the goal is to remove dirt and other residue. And thirdly, by having the sensor gate that alerts and returns the PET in the initial feeding before the shred if it contains materials other than PET. It is therefore most likely that the plastic will be clean enough for the process, but testing is needed in order to confirm it.

Shredding

The shredding of the PET plastic is done by a machine designed with that as its main purpose. It is a well known and proven way to shred plastic. The only thing that could be a concern is the size of the granules. The injection machine needs a granules size of 4x4 mm or smaller. This is solved by implementing a mesh below the blades of the shredder that only lets through pieces with correct size, or smaller. Bigger pieces will be picked up by the blades again and shredded until they also have the right size. It is therefore considered to be most likely that the shredder will be able to shred the plastic into the required size.

Drying

The biggest point of uncertainty in Plastfabriken's recycling process is how long it will take to get the granules dry enough when they are in the dryer element. According to conducted tests, the granules need to be in strong drafts of high velocity winds for 30 seconds to go from completely wet to feeling dry to the touch. But the results from these tests are not completely reliable since it was not conducted in circumstances that were very similar to the finished product. The dryer element will however have a time count that will open the valve and only let through granules when it has been drying for a certain amount of time. This amount of time needs to be determined by testing but to make sure it does not require too much time in the dryer for the granules to be dry, it is also equipped with a moisture sensor system and dehumidifiers. For these reasons, the dryer is thought to dry the granules within reasonable time, and thus meeting the requirements for the process.

Creating

A commercially available injection machine is used to mold the granules into new parts in the last step of the process. This machine has fully automatic cycle features which is a requirement. This enables the machine to mold a variation of parts by simply changing the mold. This step of the process is most assured to function as imagined because it relies on an already manufactured and tested product.

Platfabriken shows great potential to function as intended on all elements and transportations. The biggest risk for failure is the drying element where the amount of time needed to dry the granules might be longer than expected. Further testing is needed to determine if the plastic will dry reasonably fast, without the users being bored. If it turns out to be an issue, a buffer of dry plastic granulats can be needed to ensure access to raw material for the creating element.

7.1.3. Is Plastfabriken 2.0 designed to be suitable for a science centre exhibit?

The third and last sub-goal of the project was that the designed exhibit should be suitable for a science centre. This question does not regard the idea of the concept of a plastic recycling process at a science centre but instead if the design of the exhibit meets safety requirements and standards as well as having a design language for it to be displayed at a science centre. This is because the idea has already been approved and accepted by stakeholders at Universeum as a science centre exhibit. The design however, has not been validated to be suitable for a science centre. Parts of the answer can be found in the user tests results and the Plastfabriken 2.0 ES-scoring. According to findings in the user test results, the project group is confident that Plastfabriken 2.0 is designed in a way that makes it suitable for a science centre exhibition. Under the category "Emotions" in the user test results (see Appendix I), many statements confirm the design of the POI. To name a few, [k01:05], [k02:02], [k05:04] and [k06:01]. Looking at the ES-score (see 6.4.3) also supports the assumption that the design of Plastfabriken 2.0 indeed is suitable for science centres. Furthermore, showing the design for the stakeholders also adds to that. The design of Plastfabriken 2.0 thus arguably, from a user and stakeholder perspective, meets the requirements for it to be displayed at a science centre. Whether the design fulfills safety requirements and standards or not is not answered in this report. An in depth study of those subjects needs to be conducted in order to answer those questions.

7.2 Method discussion

This section discusses the methods used in the project and how the implementation of them may have affected the result.

7.2.1 The ES-method, is it reliable and applicable on all exhibits?

During the first phase of the project, a new method, the ES-method, was developed. This was done in order to collect data from observations in a structured way. The data from the ES-method was then used to find successful exhibits. From those, key features were obtained and compiled to complete the SEG-list. The SEG-list in turn was used to upgrade and develop the ES-method. With that said, the ES-method and the SEG-list affected the project outcome to a great extent. Since the ES-method was developed within the frames of this project, it is not validated in an objective way.

In summary, this can be problematic in two ways. First, the usage of the ES-method, which is not validated, arguably creates results that are not validated. Secondly, the fact that a non-validated method was used to upgrade the SEG-list which in turn was used to refine the non-validated method creates a circular reasoning. Thus, if there are inherent weaknesses, they will remain. However, to answer both objections, the results from the ES-method is in line with both interviews, observations and literature studies that were conducted during the project. The ES-method has, furthermore, proven to yield credible results when using it to evaluate exhibits at Universeum (Gothenburg), Innovatum (Trollhättan) and experimentarium (Copenhagen). Moreover, the user test confirms and gives credibility to the SEG-list. For example statements like “The user would feel that controlling the shredder would be fun” or “The user would think it to be fun to try and use the crank”, are in line with the most important *Design features* SEG. Thus, the Valuable Waste project confidently relies on the result yielded from the ES-method and SEG-list. With that said the project team is humbly aware that both the ES-method and SEG-list can be improved and validated further (see 7.4, Further work).

Both the ES-method and the SEG to a great extent concern the POIs and interaction of the exhibit. Thus, the ES-method might not yield as relevant results regarding exhibits with no POIs. For example, the ES-method might not be as applicable on museum exhibits. However, the current version of the ES-method (and thus the SEG-list) has no built-in limitations regarding size or type of exhibition (as long as it is an interactive science centre exhibit). Thus it should, from a theoretical aspect, be applicable to all science centre exhibits. The ES-method has been relevant for all of the evaluated exhibits in this project.

7.2.2 User test in Virtual Reality (VR)

The Valuable Waste project conducted a user test using VR. There are a couple of reasons for that. First, the project did not have a budget, thus, no money to get Plastfabriken 2.0 built as a model. Secondly, the project team had access to a full VR setup. Thirdly, and most important, with the means available, this was considered to be the optimal way of accomplishing an experience as close as possible to what the experience of the finished product would be. Thus, the VR user test gave valuable input and insights that could not have been gained in any other way at this stage. However, due to time limitations in combination with lack of experience of developing interactions in VR, the VR model of Plastfabriken 2.0 that the participants were subjected to, was not equipped with any interactivity. Thus, the participants were guided to the different POI:s and asked what they would have done, instead of being able to unconditionally play around with Plastfabriken 2.0. This may have had negative effects on the results. The unconditional play with Plastfabriken 2.0 would have elicited the participants unconscious and intuitive behaviours and reactions upon the POI:s. Furthermore, it would have given a sense of how Plastfabriken 2.0 was interpreted as a whole and if the intended flow of events was understood. This report claims, however, that the results from the user test are valid and trustworthy. The participants were well aware of the situation, were placed in an authentic environment (many of them exclaimed that it really looked like Universeum) and answered spontaneously. Also, they proved to have great ability to use their imagination to perform the interactions mentally. Moreover, the way in which the questions were asked and the use of probing to reach the participants' first reactions and emotions contributes to the validity of the results. Lastly, the fact that an animation of the interaction was played in VR after the participants initial reactions and comments, made room for further opinions. In summary, even if the finest details from the visceral reactions that the participants showed may have been clouded when trying to express them instead of just doing them, the result arguably contains the data that the user test was designed to reach.

One more positive aspect of making test models in 3D and evaluating them in VR is the fact that it is not resource heavy, neither the building of the models nor the changes that are made to answer the evaluation. It is also cheaper to make changes in a 3D environment than on physical models.

7.2.3 Testing for 11-year-olds with no 11-year-olds

It was unfortunately not feasible to conduct user tests on 11-year-olds due to the circumstances of the stationary VR-equipment at Boid. The compromise was to ask available parents that also had experience of taking their kids to Universeum. Thus could the parents, who know their kids very well, answer what they thought their kid would do or how they would react. A great advantage with this approach was that the test persons could answer both for their kids and for themselves. These two dimensions of the test were very valuable for the project. With that said, it is of course desirable, necessary and recommended to conduct both VR user tests and real life user tests with 11-year-olds.

7.3 The societal impact of Plastfabriken 2.0

This report argues that an exhibit as Plastfabriken 2.0 could impact behaviour and have a positive effect on the environment and thus, in the long run, a positive societal impact. The way in which Plastfabriken 2.0 is developed and designed to answer the SEG increases the chances that the users become enlightened in the way they view plastic. The hope is that they afterwards do not consider plastic waste as worthless but instead valuable. Partly from the insight that it actually can become new things but also that it is made of a scarce raw material which extraction makes a negative impact on the surrounding environment.

The making of new things at Plastfabriken 2.0 could arguably pose an ethical dilemma, namely that Plastfabriken 2.0 takes PET bottles that otherwise would have become new PET bottles, out from the bottle-to-bottle stream to instead manufacture yet another plastic product, with a completely different purpose. And who knows what the kids will do with that thing? Maybe throw it in nature! Undoubtedly, the PET bottles going into Plastfabriken 2.0 will never become bottles again, since they are no longer in the return system that takes care of the bottle-to-bottle stream in Sweden. However, nor will the kids throw the plastic thing in nature, after they have been a part of the manufacturing process of the thing and realized its potential and value. More likely they will, when the thing does not have any value for them, put it in the recycling bin, remember it and therefore never throw plastic waste anywhere other than into the plastic recycling bin. Another possible outcome could even be that users will actively collect and gather PET bottles to use in the Plastfabriken 2.0 and, as previously mentioned, thus help get plastic waste into the plastic recycling process.

7.4 Further work

In order to bring the concept forward, the next step for Boid would be physical prototyping of the POI:s. This, in order to confirm the results from the VR user test, by testing the prototypes on the aimed target group. Further, testing and verifying the functionality of the elements is recommended. That is, for example, more extensive testing regarding optimal size of the shredded granules, level of cleanness of the plastic that is needed, how dry it must be, etcetera. Furthermore, a more in depth benchmarking of off-the-shelf products is needed to determine how the construction may look like.

The Valuable Waste project urges researchers and exhibit designers to further test and develop the ES-method. The method needs to be evaluated and tested upon more exhibits. The seven proposed categories (*Gender diversity, Even Point Of Interaction (POI) attractiveness, Level of engagement, Design features, User experience, User engagement* and *Things to avoid)* covers the most important aspects that this project has found. However, there are certainly aspects that might be suitable that have not been brought up here. One obvious category that has been considered in this report but not integrated in the ES method, is the safety aspect. How can the safety aspect be incorporated in the ES method? Another interesting aspect would be form language (which would cover the pure visual features as a complement to the already existing *Design Features* category). Further questions regarding the ES-method would be; could it be expanded to be relevant for, for example, museum exhibits where there are typically fewer POI:s? To answer this question, the ES-method must be further tested and developed on such exhibits. In this project the ES method has mainly been used to identify successful features of existing exhibits, in order to find new SEG:s and in the end create a new exhibit. Does it also work the other way around in a satisfying manner? That is, does the ES-method point out aspects in existing exhibits that can be approved to make them more successful?

The SEG-list is also a tool, closely connected to the ES-method, that can and should be critically evaluated and built on. Even though this list has been a great tool in this project, it does not mean that it is feasible or applicable on every exhibit that exists or will be built. One reason for this is obviously that it has been produced from a limited number of exhibits. The SEG would certainly improve by implementing data from more exhibits. This could be done by using the ES-method. Indeed, the development of the ES-method and the SEG-list goes to a great extent hand in hand. The ES-method consists of one part that is based on observations and one part that answers whether the exhibit answers to the SEG:s. Thus, if an exhibit scores high on the part based on observation while the score on the part based on SEG:s is low, that would indicate that the exhibit contains features that could and should be added to the SEG-list. However, it is still relevant to consider that specific exhibit as not more than "somewhat successful" (which is the case if scoring highest possible on the observation based part and lowest possible on the SEG based part), since the SEG:s contains important aspects of science centre exhibits including learning and interactivity. If the SEG based part of the ES-method scores high while the observation based part scores low, one can draw two conclusions. The case could be that the SEG-list is not valid and thus does not contain successful features. Or it could be the categories in the observation based part of the ES-method that needs to be improved. However, such deviation in scoring of the different parts has not occurred during this project, which can be seen as a sign of validity. In the ideal case, with a perfect SEG-list, the level of how the exhibit answers to the SEG:s should correspond directly to how successful it is on the observation part as well. This, because in a perfect SEG all possible parameters are taken into consideration and in that case, if the exhibit answers all SEG, then it should be a successful exhibit which would be seen in the observation part of the ES-method.

8. Conclusion

Plastfabriken 2.0 is a one of a kind science centre exhibit concept where plastic PET bottles undergo a plastic recycling process and in the end becomes a new molded plastic product. Furthermore, it is a proposed embodiment of the Successful Exhibit Guidelines. The process is an industrial recycling process converted to be suitable in a science centre context. Thus, the plastic recycling process is interactive and lets the users be the creators of the new recycled product. While the users are the creators, they gain insights, enlightenment and knowledge about the plastic recycling process and the importance and benefits of recycling.

Plastfabriken 2.0 is indeed a complement to other initiatives such as Precious Plastics and Perpetual Plastic Project, that also strives for a more approachable and comprehensible view of the plastic recycling process. What such a view brings is a collective awareness that the unsustainable attitude to plastic is something that concerns all humans, and that no waste management system in the world would function without everyone contributing with their best efforts. Thus, what the users hopefully will bring from Plastfabriken 2.0 is a new perception of plastic waste as Valuable Waste.

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10. Appendices

Appendix I - User test result

Appendix II - ES-method

Appendix III - ES-ratings

Appendix IV - SEG-list

Appendix I - User test results

A. Design proposals

[i01]	**Clean the bottle**
[i01:01]	The bottle basket is too high
[i01:02]	The washingstation is too low
[i01:03]	Illustrations showing the process of cleaning will increase the understanding of what the user is meant to do
[i01:04]	It would be easier to understand the process if the bottle basket and the washing station were connected
[i01:05]	The wall around the hole for the caps makes it unpleasant to use
[i02]	**Shredder**
[i02:01]	It would, functionally, be better with only one button
[i02:02]	Let the button have a shape that recurs in the shape of the shredder so that they more easily can be linked together
[i02:03]	Let the shredder rotate always and instead use only one button to reverse the rotation
[i03]	**Crank**
[i03:01]	Use a mirror that would enable one to see the top of the conveyor belt as well
[i03:02]	Have the conveyer belt in an angle that would allow one to see the top of it
[i04]	**Cleaning**
[i04:01]	There should be something where the user can put their feet to take take brace against themselves
[i04:02]	The POI could instead be a pull lever
[i04:03]	Let the pull strap be located at the back side instead to cover less of the machine
[i04:04]	The pull strap should take an more intricate path to be more exciting to watch
[i04:05]	The handle stopper should encroach less on the space where the user would want to put his or her hands
[i05]	**Drying**
[i05:01]	Emphasise more on the interaction or function where all granules is meant to be blown up the tube when the drying is finished
[i06]	**Fish Stair**
[i07]	**Create**
[i07:01]	The user should be able to see the molded part before it goes away to the shop

B. User actions

[j01]	**Clean the bottle**
[j01:01]	The user will try to grab the bottles when first introduced to this POI
[j01:02]	The user will try to push, twist and turn on the washing station
[j01:03]	The user will inspect other users before acting. If no other user is available to inspect, the user will interact even though he or she don’t understand the full function of the POI
[j01:04]	The user will try and use the washing station to splash water onto other users
[j01:05]	The user will peak into the hole and try to see what it is on the other side
[j02]	**Shredder**
[j02:01]	The user will push the buttons to try and figure out its functions
[j02:02]	The user will collaborate with other users to try and shred as much plastic bottles as possible
[j02:03]	The user will study the element in action before self interacting with it
[j03]	**Crank**
[j03:01]	If the motion is too physically demanding (much resistance) the user would interact less with it than if it had low resistance
[j03:02]	The user will want to try and get the granules to the end as quickly as possible by cranking the fastest possible
[j03:03]	The user will crank three rotations before asking someone who he or she is there with to continue the cranking and stand by to look at the granules reach the end
[j04]	**Cleaning**
[j04:01]	They will try to figure out the intention of the element even if he or she don't understand the task on forehand
[j04:02]	The user will pull the handle
[j04:03]	The user will grab the handle and push the different things
[j04:04]	The user will try to figure out the interaction if it wouldn't have had any movement by itself, showing what was meant to be done

[j05]	**Drying**
[j05:01]	The user will push the buttons
[j05:02]	The user and a friend to the user will try to max out the blow in order to blow all granules out the pipe in the top
[j06]	**Fish Stair**
[j06:01]	The user will pull both handles
[j06:02]	The user will collaborate with another user to pull one handle each
[j07]	**Create**
[j07:01]	The user will push the button

C. Emotions

[k01]	**Clean the bottle**
[k01:01]	Water if fun
[k01:02]	The user might not enjoy using a reverse vending machine
[k01:03]	The user might enjoy using a reverse vending machine
[k01:04]	The user will feel amused when doing this process
[k01:05]	The user will think the "clean the bottle" process is very fun
[k02]	**Shredder**
[k02:01]	The user will feel that destroying something is fun
[k02:02]	The user will feel that controlling the shredder would be fun
[k03]	**Crank**
[k03:01]	The user will think it's fun to try and use the crank
[k03:02]	The user will feel satisfied by accomplishing to move the granules to the end of the conveyor belt
[k03:03]	The user will enjoy cranking the crank
[k04]	**Cleaning**
[k04:01]	The user will not feel intimidated to try and pull the handle even if the handle stopper occupies some of the gripping area
[k04:02]	The user will not feel intimidated to try the interaction once he or she feels comfortable in the space
[k04:03]	The user will think that this would be fun in general
[k04:04]	Things that spins are perceived as fun by the user

[k05]	**Drying**
[k05:01]	The user will enjoy discovering that the buttons cohere to a air nozzle and that each button activates one certain nozzle
[k05:02]	The user will not be intimidated to try the interaction
[k05:03]	The user will think that it's fun to interact with this element but not for too long
[k05:04]	The user will think it is to try and blow the granules out the top of the chamber
[k06]	**Fish Stair**
[k06:01]	This element will be fun for the user to interact with
[k06:02]	Using this element might raise a sense of challenge that will be fun
[k06:03]	It will be fun for the user to see how the concept of a fish stair works
[k07]	**Create**
[k07:01]	The user will think it is fun to get something after completing the process
[k07:02]	The user will feel like it was thanks to he or she that the part was produced and proud over it
[k07:03]	The user wouldn't feel mind blown about having seen the process
[k07:04]	The user will think it was fun to be part of the process
[k07:05]	The user will enjoy being able to see how plastic recycling works since it is something that is difficult to experience or see
[k07:06]	The user will think it was very exciting that a new part is created from recycled plastic bottles

D. Analyzes

[l01]	**Clean the bottle**
[l01:01]	The user might be distracted by the washing station which might result in them not noticing the hole where the bottle is intended to enter
[l01:02]	This area is going to be very wet, but that might not pose a problem
[l01:03]	Having a wall covering the rest of the process will make the users anxious to discover and see the rest of it which will make the users explore more of the exhibit and not just the Clean the bottle station
[l02]	**Shredder**
[l02:01]	The user will want to see what will happen to

	the bottle when entering the shredder
[I02:02]	The user would want to know what will happen before he or she tries it
[I02:02]	The user will understand that the the goal is to shred the bottle
[I03]	**Crank**
[I03:01]	If the cranking would have high resistance the user will feel rejected to crank a lot
[I03:02]	The user would immediately understand what to do at this POI
[I03:03]	The user will not be careful with the equipment since it is placed at a science centre and here it is ok to be rough and try everything that is possible to try
[I04]	**Cleaning**
[I04:01]	For the interaction to function properly it requests that the user grabs the handle with both hands and pulls
[I04:02]	If interaction with the element is too physically demanding the user will get tired of trying it
[I05]	**Drying**
[I05:01]	The vertical tube in the top invites the user to try and get the granules there
[I05:02]	The user will think this element is less challenging than the rest of them
[I05:03]	The user is not going to be attracted to compete at this element since it is not physically demanding
[I05:04]	The user will probably sense a feeling of game playing with trying to get the granules out the top tube
[I06]	**Fish Stair**

[I06:01]	The principle of the fish stair is fun
[I06:02]	It is a physical challenge for the user with a direct link to something visually which is a instant reward
[I06:03]	The element feels a bit tricky to understand and to conduct the interaction correctly
[I06:04]	This element isn't really necessary for the process
[I07]	**Create**
[I07:01]	The part is a direct connection to the recycling process so by having the part, the user will remember the process
[I07:02]	If the part is fun in some way, the user will want it
[I07:03]	The user will probably think back and remember that the part was made by recycled plastic bottles when using it
[I07:04]	The user will probably remember most of the steps in the process
[I07:05]	Since the exhibit holds so many elements and POI, the user will probably only remember a few of them and not all
[I07:06]	The user could have difficulties to remember the entire process just by looking at the molded part
[I07:07]	The molded part is a clear reminder of that is was created from recycled plastic bottles
[I07:08]	The user might not have been disappointed if he or she didn't get to keep the molded part because he or she didn't expect it from the beginning

Appendix II - Exhibit Scoring-Method

Exhibit Scoring-Method

Step 1. User information

Time from start (minutes)	0	20	40	60	80
Number of active users count	4	1	6	2	10
Number of passive spectators	1	0	1	0	2
Number of points of interactions	4	4	4	4	4
Number of points of interactions being user engaged	3	1	2	1	4
Number of active female users	2	1	3	1	1
number of active male users	2	0	3	1	9

The first part when conducting the ES-method is to observe the user interaction over at least five occasions of measurements. These should be at least twenty minutes apart.

Number of active users
number of users that are actively interacting and engaging in the exhibit.

Number of active male users
How many of the active users are males.

Number of points of interactions (POIs):
The count of how many points that are available for the user to interact with the exhibit. If the number of active users are less then number of POIs, the value inserted in this cell should be equal to number of active users.

Number of POIs being user engaged
How many points where an user actively interacts with the exhibit.

Number of active spectators
Users that actively interpret or consume an exhibit without direct interaction at any of the POIs.

Number of passive spectators
Number of user that want to engage with an exhibit but are, for some reason, hindered to. For example because of no POIs being available or it being too complex

Number of active female users
How many of the active users are females.

Step 2. User calculations

Gender diversity (2)	0,5	1	0,5	0,5	0,9	0,32
Even POI attractiveness (2)	0,6	0,25	0,43	0,25	0,83	4,7
Level of engagement (2,5)	0,8	1	0,86	1	0,83	9

Gender diversity:
This value determines how even the difference between female and male users is. A perfectly even partition of female and male users yield a value of 0,5 (50% female and 50% male users). And in a situation where only female or male users are present the value will be 1 (100% of one gender).

Even POI attractivenesstegrality:
This value determines how well the exhibit is able to make as many user as possible to be active at as many POI as possible. It yields a value between 0 and 1 where 1 means that the exhibit is able to accomplish this fully.

Level of engagement:
This value determines how well the exhibit attracts to use. Passive spectators are visitors that want to engage with the exhibit but for some reason chooses not to. If the exhibits holds no passive spectators and only active users, it will yield a value of 1.

Gender diversity:
Variables included:
Number of female users = x
Number of male users = y

Calculation:
If(x > y) then; (x / (x + y)
If(x < y) then; (y / (x + y)
If(x = y) then; "0,5"

Level of engagement:
Variables included:
Number of active users count = x
Number of passive spectators = y

Calculation:
(x / (x + y))

Even POI attactiveness:
Variables included:
Number of active users count = x
Number of passive spectators = y
Number of POIs = z
Number of POIs being user engaged = i

Calculation:
(x/(x+y))*(i/z)

Step 3. Category average

						Avg.
Gender diversity (2)	0,5	1	0,5	0,5	0,9	0,32
Even POI attractiveness (2)	0,6	0,25	0,43	0,25	0,83	4,7
Level of engagement (2,5)	0,8	1	0,86	1	0,83	9

After the last time of observations (in this example, after 80 minutes) the five values of each category should be given an average. This is done by adding all five values in each respectively category and divide the sum by 5. This value is then be multiplied by 10 in order to make it more easily interpreted as a point system value. The resulting value is written in the "Avg." column and called the average value of that certain category. To get the correct average value of the gender diversity however, the average of the five numbers need to be subtracted by 0,5 and then multiplied by 2. Then subtracting the receiving value from 1 and multiplying everything with 10 will yield its correct value.

Average value of gender diversity example:
The fives values of gender diversity average: 0,71
(1 - (0,71 - 0,5) * 2) * 10 = 5,8

This has to be done in order to take into account that the gender diversity has a minimum and maximum interval between 0,5 and 1, compared to the two others having it between 0 and 1.

[1.0]	DESIGN FEATURES (5,5)	Level of acomplishment	Guideline weight	Score (330)
[1.1]	The user should be able to do stuff by themselves	3	9,5	28,5
[1.2]	The exhibit should contain things that users doesn't see in their ordinary life	2	7	14
[1.3]	The exhibit should involve as many parameters (senses) as possible	5	2,5	12,5
[1.4]	The exhibit should contain hands-on experiences	3	6	18
[1.5]	The visitors should be allowed and encouraged to touch and feel things	2	7,5	15
[1.6]	Utilize the muscle power of the visitors and use them as power input	4	6	24
[1.7]	The exhibit should encourage collaboration, between the users and their significant others	1	3,5	3,5
[1.8]	The technology should be easy to use	5	7	35
[1.9]	The exhibit should effectively support collaboration	0	3	0
[1.10]	The exhibit should be designed to minimize the need for signs with extensive text chunks	3	3,5	10,5
[1.11]	The exhibit should effectively support interaction.	2	10,5	21
[1.12]	The interactive stations should reset to default position independent of the visitors	1	0	0

[2.0]	DESIRED USER EXPERIENCE (4,5)	Level of acomplishment	Guideline weight	Score (50)
[2.1]	The exhibit should consist of storytelling and narrative creation	2	0,5	1
[2.2]	The exhibit should elicit laughter	3	1	3
[2.3]	The exhibit should generate aha-moments	1	3,5	3,5
[2.4]	Children should find the learning experience enjoyable	4	3	12
[2.5]	The exhibition should utilize and encourage the creativity and imagination of the visitors	5	2	10

[4.0]	THINGS TO AVOID (1)	Level of acomplishment	Guideline weight	Score (180)
[4.1]	The design of the exhibition should not resemble inappropriate things (eg fallo)	2	1,5	3
[4.2]	Avoid nooks where visitors can hide things	2	1	2
[4.3]	The exhibit should not include loose theft-prone objects	3	4	12
[4.4]	The exhibit should not include loose objects	1	2	2
[4.5]	The amount of needed staff supervision should be kept at minimum	4	6,5	26
[4.6]	If signs are necessary, they should not score higher than 30 according to LIX	5	5	25
[4.7]	Passive and voiceless material interpreting	2	4,5	9
[4.8]	The exhibit should be unobtrusive	3	4	12
[4.9]	The exhibit should be easy to understand	4	7,5	30

[3.0]	USER ENGAGEMENT (3,5)	Level of acomplishment	Guideline weight	Score (15)
[3.1]	The exhibit should be self explanatory	2	1	2
[3.2]	Children should be actively interpreting material culture for themselves	1	0,5	0,5
[3.3]	Children should learn from the exhibit	4	1,5	6

Level of accomplishment

1 Not at all
2 A little
3 Somewhat
4 Almost completely
5 Completely

ES-rating

Step 4. Level of accomplishment - SEG

The fourth step is to fill in how well the exhibit succeeds with following the Successful Exhibit Guidelines, in a scale from 1 - 5. For example: “The exhibit succeeds somewhat (3) with letting the user to be able to do stuff themselves [1.1]”. To calculate the score of each guideline, the “level of accomplishment” is multiplied with “guideline weight” and then written in the “score column”.

Step 4. Compiling final results

	Score	Max score	Avg.	Weight	IES	Max	%
Gender diversity	-	-	5,8	2	11,6	20	0,6
Exhibit integrality	-	-	4,9	2	9,8	20	0,49
Level of engagement	-	-	9,2	2,5	23	25	0,92
Sum (Users & POI)	-	-	-	-	44,4	65	0,69
DESIGN FEATURES	182	330	5,5	5,5	30,3	55	0,55
DESIRED USER EXPERIENCE	29,5	50	5,9	4,5	26,6	45	0,59
USER ENGAGEMENT	8,5	15	5,7	3,5	20	35	0,57
THINGS TO AVOID	121	180	6,7	1	6,7	10	0,67
Sum					128	210	0,61

The last step is to complete the summary of all the scores. This is done by completing the last chart (see table 7). The first three rows are completed with values gotten from the quantitatively collected categories.

The next coming column represents the categories’ Individual Exhibit Score (IES). This score is calculated by multiplying their average value with their individual category weight and then multiplying this value by ten.

The value in the cells to the right of the individual Exhibit Score is the maximum achievable individual Exhibit Score. The cell to the furthest right (column: “%”) represents the percentage of how well the individual Exhibit Score compares to its maximum. It is calculated by dividing the Individual Exhibit Score with the maximum Individual Exhibit Score. This value is very usable when backtracking an Exhibit Score to see where improvements can be done to get a higher score. Maybe the, as in the example, level of engagement has scored really high on their IES (0,92 = 92% of maximum), while the Even POI attractiveness only scored 49%. Conclusions that can be drawn are that there might be some improvements that can be done to some of the POI so that more users feel intrigued to use all POIs on the exhibit.

The row called “Sum (Users & POI)”in this chart holds the total scoring of the Gender diversity, Even POI attractiveness and Level of engagement and shows that the exhibit succeeds to 69% with accomplishing perfect gender diversity, Even POI attractiveness and level of engagement.

The four categories from the SEG-list have, in comparison to the three quantitatively collected categories, a “score” column where the total scoring from each category is shown. In order to calculate the average scoring “Avg.”, the maximum achievable score “Max score” is also presented here. The “Avg.” is calculated by dividing the “score” with the “max score” and then multiplying it by 10. The remaining calculations (IES and percentage) are calculated the same way as for the top three categories.

The last row, “Sum”, shows the total exhibit scoring, where the IES in this case represents the total Exhibit Score (ES) of the entire exhibit. And the “%” show how well the exhibit succeeds with achieving highest possible score. In the example, the ES of this exhibit is 0,61 which means that it is 39% off from scoring the absolute max. To make use of these numbers more concrete, the Success level scale has been developed.

Step 5. Reading the results

By analyzing exhibits, using the ES-method and discovering their ES value, a lot of conclusions can be made. Points of improvements can be accurately pointed towards certain areas of flaws in the exhibit design. Or, as in this project, well scoring exhibits can be recognized and further analyzed to see why they have received a high score. The findings can then be incorporated into new exhibit designs.

Appendix III - ES-ratings

A. Hälsan (Universeum)

Time from start (minutes)	0	20	40	60	80
Number of active users count	77	62	53	65	49
Number of passive spectators	8	6	6	7	3
Number of points of interactions	21	21	21	21	21
Number of points of interactions being user engaged	17	16	11	14	11
Number of active female users	30	36	29	38	23
number of active male users	47	26	24	27	26
Gender diversity (2)	0,61	0,58	0,55	0,58	0,53
Even POI attractiveness (2)	0,73	0,69	0,47	0,6	0,49
Level of engagement (2,5)	0,91	0,91	0,9	0,9	0,94

[1.0]	DESIGN FEATURES (5,5)	Level of acc-omplishment	Guideline weight	Score (330)
[1.1]	The user should be able to do stuff by themselves	4	9,5	38
[1.2]	The exhibit should contain things that users doesn't see in their ordinary life	1	7	7
[1.3]	The exhibit should involve as many parameters (senses) as possible	3	2,5	7,5
[1.4]	The exhibit should contain hands-on experiences	3	6	18
[1.5]	The visitors should be allowed and encouraged to touch and feel things	2	7,5	15
[1.6]	Utilize the muscle power of the visitors and use them as power input	4	6	24
[1.7]	The exhibit should encourage collaboration, between the users and their significant others	5	3,5	17,5
[1.8]	The interaction should be easy to use	5	7	35
[1.9]	The exhibit should effectively support collaboration	3	3	9
[1.10]	The exhibit should be designed to minimize the need for signs with extensive text chunks	4	3,5	14
[1.11]	The exhibit should effectively support interaction.	5	10,5	52,5
[1.12]	The interactive stations should reset to default position independent of the visitors	5	0	0

[2.0]	DESIRED USER EXPERIENCE (4,5)	Level of acc-omplishment	Guideline weight	Score (50)
[2.1]	The exhibit should consist of storytelling and narrative creation	2	0,5	1
[2.2]	The exhibit should elicit laughter	4	1	4
[2.3]	The exhibit should generate aha-moments	1	3,5	3,5
[2.4]	Children should find the learning experience enjoyable	4	3	12
[2.5]	The exhibition should utilize and encourage the creativity and imagination of the visitors	3	2	6

[3.0]	USER ENGAGEMENT (3,5)	Level of acc-omplishment	Guideline weight	Score (15)
[3.1]	The exhibit should be self explanatory	4	1	4
[3.2]	Children should be actively interpreting material culture for themselves	1	0,5	0,5
[3.3]	Children should learn from the exhibit	2	1,5	3

[4.0]	THINGS TO AVOID (1)	Level of acc-omplishment	Guideline weight	Score (180)
[4.1]	The design of the exhibition should not resemble inappropriate things (eg fallo)	5	1,5	7,5
[4.2]	Avoid nooks where visitors can hide things	5	1	5
[4.3]	The exhibit should not include loose theft-prone objects	5	4	20
[4.4]	The exhibit should not include loose objects	5	2	10
[4.5]	The amount of needed staff supervision should be kept at minimum	5	6,5	32,5
[4.6]	If signs are necessary, they should not score higher than 30 according to LIX	2	5	10
[4.7]	Avoid passive and voiceless material interpreting	4	4,5	18
[4.8]	The exhibit should not be perceived as frightening	4	4	16
[4.9]	The exhibit should be easy to understand	4	7,5	30

B. Circus Fysikus (Experimentarium)

Time from start (minutes)	0	20	40	60	80
Number of active users count	12	34	10	4	27
Number of passive spectators	1	3	0	0	3
Number of points of interactions	12	16	10	4	16
Number of points of interactions being user engaged	4	10	5	1	14
Number of active female users	9	15	4	4	16
number of active male users	3	19	6	0	11
Gender diversity (2)	0,75	0,56	0,6	1	0,59

Even POI attractiveness (2)	0,31	0,57	0,5	0,25	0,79
Level of engagement (2,5)	0,92	0,92	1	1	0,9

[1.0]	DESIGN FEATURES (5,5)	Level of acc-omplishment	Guideline weight	Score (330)
[1.1]	The user should be able to do stuff by themselves	5	9,5	47,5
[1.2]	The exhibit should contain things that users doesn't see in their ordinary life	4	7	28
[1.3]	The exhibit should involve as many parameters (senses) as possible	1	2,5	2,5
[1.4]	The exhibit should contain hands-on experiences	4	6	24
[1.5]	The visitors should be allowed and encouraged to touch and feel things	4	7,5	30
[1.6]	Utilize the muscle power of the visitors and use them as power input	4	6	24
[1.7]	The exhibit should encourage collaboration, between the users and their significant others	3	3,5	10,5
[1.8]	The interaction should be easy to use	5	7	35
[1.9]	The exhibit should effectively support collaboration	3	3	9
[1.10]	The exhibit should be designed to minimize the need for signs with extensive text chunks	5	3,5	17,5
[1.11]	The exhibit should effectively support interaction.	5	10,5	52,5
[1.12]	The interactive stations should reset to default position independent of the visitors	2	0	0

[2.0]	DESIRED USER EXPERIENCE (4,5)	Level of acc-omplishment	Guideline weight	Score (50)
[2.1]	The exhibit should consist of storytelling and narrative creation	4	0,5	2
[2.2]	The exhibit should elicit laughter	3	1	3
[2.3]	The exhibit should generate aha-moments	5	3,5	17,5
[2.4]	Children should find the learning experience enjoyable	4	3	12
[2.5]	The exhibition should utilize and encourage the creativity and imagination of the visitors	5	2	10

[3.0]	USER ENGAGEMENT (3,5)	Level of acc-omplishment	Guideline weight	Score (15)
[3.1]	The exhibit should be self explanatory	4	1	4
[3.2]	Children should be actively interpreting material culture for themselves	2	0,5	1
[3.3]	Children should learn from the exhibit	4	1,5	6

[4.0]	THINGS TO AVOID (1)	Level of acc-omplishment	Guideline weight	Score (180)
[4.1]	The design of the exhibition should not resemble inappropriate things (eg fallo)	4	1,5	6
[4.2]	Avoid nooks where visitors can hide things	5	1	5
[4.3]	The exhibit should not include loose theft-prone objects	1	4	4
[4.4]	The exhibit should not include loose objects	1	2	2
[4.5]	The amount of needed staff supervision should be kept at minimum	5	6,5	32,5
[4.6]	If signs are necessary, they should not score higher than 30 according to LIX	5	5	25
[4.7]	Avoid passive and voiceless material interpreting	3	4,5	13,5
[4.8]	The exhibit should not be perceived as frightening	4	4	16
[4.9]	The exhibit should be easy to understand	5	7,5	37,5

C. Hamnen (Experimentarium)

Time from start (minutes)	0	20	40	60	80	
Number of active users count	24	6	19	23	14	
Number of passive spectators	1	0	0	2	1	
Number of points of interactions	24	6	19	23	14	
Number of points of interactions being user engaged	22	6	17	22	14	
Number of active female users	9	2	9	5	6	
number of active male users	15	4	10	18	8	
Gender diversity (2)	0,63	0,67	0,53	0,78	0,57	0,64
Even POI attractiveness (2)	0,88	1	0,89	0,88	0,93	9,2
Level of engagement (2,5)	0,96	1	1	0,92	0,93	9,6

[1.0]	DESIGN FEATURES (5,5)	Level of acc-omplishment	Guideline weight	Score (330)
[1.1]	The user should be able to do stuff by themselves	4	9,5	38
[1.2]	The exhibit should contain things that users doesn't see in their ordinary life	3	7	21
[1.3]	The exhibit should involve as many parameters (senses) as possible	1	2,5	2,5
[1.4]	The exhibit should contain hands-on experiences	2	6	12
[1.5]	The visitors should be allowed and encouraged to touch and feel things	2	7,5	15
[1.6]	Utilize the muscle power of the visitors and use them	4	6	24

	as power input			
[1.7]	The exhibit should encourage collaboration, between the users and their significant others	4	3,5	14
[1.8]	The interaction should be easy to use	3	7	21
[1.9]	The exhibit should effectively support collaboration	4	3	12
[1.10]	The exhibit should be designed to minimize the need for signs with extensive text chunks	2	3,5	7
[1.11]	The exhibit should effectively support interaction.	5	10,5	52,5
[1.12]	The interactive stations should reset to default position independent of the visitors	4	0	0

[2.0]	DESIRED USER EXPERIENCE (4,5)	Level of acc-omplishment	Guidelin e weight	Score (50)
[2.1]	The exhibit should consist of storytelling and narrative creation	5	0,5	2,5
[2.2]	The exhibit should elicit laughter	2	1	2
[2.3]	The exhibit should generate aha-moments	2	3,5	7
[2.4]	Children should find the learning experience enjoyable	4	3	12
[2.5]	The exhibition should utilize and encourage the creativity and imagination of the visitors	3	2	6

[3.0]	USER ENGAGEMENT (3,5)	Level of acc-omplishment	Guideline weight	Score (15)
[3.1]	The exhibit should be self explanatory	3	1	3
[3.2]	Children should be actively interpreting material culture for themselves	2	0,5	1
[3.3]	Children should learn from the exhibit	3	1,5	4,5

[4.0]	THINGS TO AVOID (1)	Level of acc-omplishment	Guideline weight	Score (180)
[4.1]	The design of the exhibition should not resemble inappropriate things (eg fallo)	4	1,5	6
[4.2]	Avoid nooks where visitors can hide things	2	1	2
[4.3]	The exhibit should not include loose theft-prone objects	2	4	8
[4.4]	The exhibit should not include loose objects	1	2	2
[4.5]	The amount of needed staff supervision should be kept at minimum	4	6,5	26
[4.6]	If signs are necessary, they should not score higher than 30 according to LIX	4	5	20
[4.7]	Avoid passive and voiceless material interpreting	4	4,5	18
[4.8]	The exhibit should not be perceived as frightening	5	4	20
[4.9]	The exhibit should be easy to understand	2	7,5	15

Appendix IV - SEG-list

The Guidelines are here presented. The top weighted guidelines are marked in different shades of green; most important, second most important, third most important.

A. Design features

[1.1]	The user should be able to do stuff by themselves
[1.2]	The exhibit should contain things that users doesn't see in their ordinary life
[1.3]	The exhibit should involve as many parameters (senses) as possible
[1.4]	The exhibit should contain hands-on experiences
[1.5]	The visitors should be allowed and encouraged to touch and feel things
[1.6]	Utilize the muscle power of the visitors and use them as power input
[1.7]	The exhibit should encourage collaboration, between the users and their significant others
[1.8]	The interaction should be easy to use
[1.9]	The exhibit should effectively support collaboration
[1.10]	The exhibit should be designed to minimize the need for signs with extensive text chunks
[1.11]	The exhibit should effectively support interaction.
[1.12]	The interactive stations should reset to default position independent of the visitors

B. User experience

[2.1]	The exhibit should consist of storytelling and narrative creation
[2.2]	The exhibit should elicit laughter
[2.3]	The exhibit should generate aha-moments
[2.4]	Children should find the learning experience enjoyable
[2.5]	The exhibition should utilize and encourage the creativity and imagination of the visitors

C. User engagement

[3.1]	The exhibit should be self explanatory
[3.2]	Children should be actively interpreting material culture for themselves
[3.3]	Children should learn from the exhibit

D. Things to avoid

[4.1]	The design of the exhibition should not resemble inappropriate things (eg fallo)
[4.2]	Avoid nooks where visitors can hide things
[4.3]	The exhibit should not include loose theft-prone objects
[4.4]	The exhibit should not include loose objects
[4.5]	The amount of needed staff supervision should be kept at minimum
[4.6]	If signs are necessary, they should not score higher than 30 according to LIX
[4.7]	Avoid passive and voiceless material interpreting
[4.8]	The exhibit should not be perceived as frightening
[4.9]	The exhibit should be easy to understand