The Fashion Stage

How to design an on-body projection exhibit for effective learning about sustainable fabrics in the museum

Master's Thesis
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The motivational drive for this research work partly stems from an appreciation for our physical world. I belief that real experiences in the now are at the core of a meaningful life. However, with the coming of smartphones and computers, our attention has become somewhat scarce. We can spend the whole day being absorbed by a screen, without even realizing how much time has passed. Currently, alternative realities are on the rise as well. In such digital worlds, you can do anything you want, be anything you want, experience anything you want. However, with the coming of such flawless alternate worlds, we should not forget about the wonders that can be found in the everyday life experiences. Perhaps, some of the depth of life actually lies in the imperfect, real moments. During this thesis, I learned how technology and the real world can become one. My goal has become to design a technology that amplifies reality, rather than making an escapism to an artificial space. I think there is tremendous beauty to discover in the mergeance of the digital and the real world, and hope to contribute to the magic of on-body projections with this work.

"Wherever you are, be there totally" Eckhart Tolle [115]

Abstract

It is clear that humans are facing great challenges in their existence as a species on the planet, and raising awareness of sustainable developments can accelerate progression towards a better world. Museums have a unique position to educate the general public about positive change through immersive exhibits. In this research, an opportunity is identified to study the potential of on-body projections for more impactful museum exhibits. Previous works suggested that projections can provide a deeper sense of unity with augmented objects [7, 8], but the specific influence of on-body features has not yet been explored. Neither has the use of on-body technology been explored in the context of a museum exhibit on sustainable development. Therefore, this study found an opportunity to explore whether on-body projections can give museums an additional technique to make an emotional impact on museum visitors. This is studied through the design of an on-body projection installation for sustainable fashion, which is located in a new exhibition 'One Planet NOW!' in Museon, a museum in the Hague. The aim of the installation is to let visitors discover sustainable clothes made from various unconventional materials. The development of the exhibit produced design lessons that can support future researchers aiming to utilize on-body projections in museum exhibits. Additionally, the research provided a better understanding of the perceived emotional impact of on-body projections and the identification of contributing factors. This was done by conducting a focus group that included the Inclusion of Other in the Self scale (IOS) by Aron et. al [102]. Indications were found that on-body projections can give visitors a deeper sense of emotional involvement with the exhibit content. Visitors reported that they felt a sense of personal involvement, and felt increased empathy, when the exhibit content was projected onto their bodies. Moreover, the extent that on-body projections contribute to the learning opportunity in the exhibit is evaluated using the the Museum Experience Scale (MES) by Othman et. al [29]. Increased engagement was observed for the installation with on-body projections, but the results for a meaningful experience, knowledge, and emotional connection were non-significant. Several issues that require improvements to optimize the installation, are given as a possible explanation for these results. The thesis concludes that there could be high potential for the use of on-body projections in museum exhibits, but further improvements are needed to optimally utilize their benefits. Finally, recommendations are given for further research on on-body projections for museum exhibits.

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Section 1

Project overview

1 Introduction

1.1 Thesis assignment

Global challenges, such as climate change, increasingly require an urgent transformative sustainable shift in our society. Museums are informal education institutions that can play a key role in addressing the urge for sustainable development to the general public. Museums, have always been a space in which people are enabled to explore the world. In recent years, museums have shifted from a place where conservation artifacts are passively showcased [1, 2], to a place where people are actively invited to expand their knowledge, shape their values, and reflect on their attitudes [3]. By offering engaging learning experiences at their exhibits, museums can stimulate the involvement of the public with sustainable issues. Moreover, interactive technologies can enhance the impact of exhibits by making the educational issues come to life through interactive and immersive experiences.

This project aims to expand our understanding of how to design interactive installations in the museum to support learning about sustainable development. This is achieved by following the design process of an exhibit about sustainable fashion. Museon, a museum in The Hague, requested to develop an additional installation, that introduces visitors to unconventional materials that can be used for the production of fashion items. The interactive installation will be part of a replicated fashion store at the upcoming exhibition 'One Planet NOW'. The museum requested that the installation supports the sustainable learning goals in an engaging interactive experience with the use of novel technology. As a design direction, the use of on-body projections in the exhibit as a design direction was suggested.

The first part of this document contains a literature research for a better understanding of the research context. First, I aimed to understand what approach can be taken to involve the general public with sustainable development. The key findings are the importance of emotional arousal [16, 22], and the focus on positive communication in exhibits for effective environmental learning outcomes [32, 34]. Second, insights were gathered from existing theories on museum learning. The framework by Csikszentmihalyi has been reviewed, explaining the principles that contribute to effective learning in the museum [36]. In particular, the framework addresses the crucial role of intrinsically motivated visitors. Moreover,

the framework explains how sensory, emotional and intellectual attributes can increase visitors' motivation to engage with exhibits. Furthermore, the literature work was expanded by reviewing several studies that address these attributes. Lastly, how technology can contribute to the effectiveness of museum exhibits was studied. It was found that there is a need for better integration between interactive technologies and the museum environment, and drawing attention away from the museum artifacts is a point of concern for technology [42, 56, 64].

At this stage, the design direction for on-body projections in the installation was validated based on its assessed potential. There are several benefits to projection-based installations in the museum for addressing the objectives of this assignment. Projection-based technologies can be seamlessly integrated with the museum environment, offering shared and immersive exhibit experiences [4, 5, 6]. Moreover, on-body projections fit the objective to enhance engagement with sustainable development, as they could literally unify the visitor and the virtual content for the sustainable materials [82]. Finally, the primary objects of the exhibit are fashion items worn by the visitor, making on-body projections an applicable design direction. However, little is known about how on-body technology could be adopted in a museum exhibit on sustainable development. Therefore, on-body projections will be at the core of the installation design, to produce insightful design lessons for future researchers. This makes it one of the first studies to explore in-depth how visitors' bodies can be utilized for effective learning in museums.

The practical goal of the assignment was to design an on-body projection exhibit that could engage visitors while learning about sustainable fabrics used in fashion. Therefore, the extent the on-body exhibit enabled an effective learning opportunity was assessed. This was done for the exhibit as a whole, and the contribution of on-body projections was evaluated separately. At the same time, the assignment provided a novel research opportunity to explore the use of on-body projections for increased emotional arousal in the exhibit experience. A study on advancing object projection-mapping, and a study on physiotherapy education have found indications that projections onto objects, or bodies, can evoke a deeper sense of connection with virtual content [7, 8]. This showed that there might be potential for museums displaying sustainable content onto visitors through on-body projections. However, the previous studies did not evaluate how on-body projections contribute to these emotional effects. Moreover, previous studies only evaluated on-body projection systems as a whole, instead of evaluating the impact of this technology separately. Therefore, as a research gap, the emotional effects of on-body projections are explored, as well as their contribution to the learning opportunity in the exhibit. The ultimate goal of this work is to enable more effective learning opportunities in sustainable development through exploring on-body

projections.

1.2 Goals

Research goals

The goal of this thesis is threefold. First, the goal is to learn more about effectively integrating on-body projections in a museum installation. A knowledge foundation is built on immersive learning opportunities in modern museums, and how on-body projections might be able to play a role in enhancing the impact of exhibits. Second, an interactive installation is designed and developed with the use of this theoretical foundation. Throughout this process, design lessons were produced that can be insightful for future researchers aiming to integrate on-body projections in their work. Thirdly, the installation was used to study the effect of on-body projections on the learning opportunity of the sustainable exhibit. Qualitative and quantitative user research is conducted to evaluate the on-body projections with actual visitors at the exhibit. The on-body projections in the installation are compared to more conventional projections on a flat surface, to better understand its separate impact on the visitor experience. In the qualitative study, the visitor's emotional involvement with the projections is explored, in particular their sense of connection with the exhibit content, as this is an important predictor for effective environmental learning [16, 22]. For the quantitative analysis, the contribution of on-body projections on the learning opportunity is evaluated in comparison to on-screen projections with the use of the Museum Experience Scale (MES), which measures internal motivators that are crucial to the free-choice learning environment of museums [36]. The thesis concludes with the findings throughout the design process and evaluation studies, and provides recommendations for future research on on-body projections in museum exhibits.

Research contributions

As explained, the aim of this thesis is to make three contributions to HCI research for studying projection-based technologies in museums. A summary of the contributions is given. First, a knowledge foundation is build on how to develop engaging exhibits for sustainable development in a modern museum. This is done through reviewing literature and previous work. Second, design lessons will be drafted on how to integrate on-body projections in a museum exhibit effectively. This can be insightful for future researchers aiming to integrate on-body projections in museum exhibits. The design lessons will be gathered throughout the design and development of the installation. Third, the contribution of on-body projections on the impact of the exhibit will be evaluated through an exploratory study. In

particular, the goal is to understand whether visitors' emotional experience with the sustainable content is altered by the projections, and to identify the factors that play a role.

Research questions

To explore the potential of projection-based interactive technology in a museum exhibit, this thesis aims to address the following research question:

How to design an on-body projection exhibit for effective learning about sustainable fabrics at the museum?

Next, sub-questions were drafted to support the research work. These are as follows:

1. How to design an on-body projection exhibit that adopts the principles for effective learning about sustainable development?
2. Which design lessons can be drawn when utilizing visitors' bodies as a museum exhibit display?
3. How do the on-body projections affect visitors' emotional experience with the exhibit content?
4. To what extent is the on-body exhibit effective in terms of enabling a learning opportunity at the exhibit?

Therefore, this work aims to contribute to HCI research in the following ways:

- Building a knowledge foundation on how to design effective exhibits for sustainable development in a modern museum
- Understanding the role of technology in museums, and building a rationale for utilizing on-body projections for the learning goals of the exhibit
- Providing design lessons on the implementation of on-body projections in a museum installation, that can be insightful for future researchers.
- Exploring how on-body projections contribute to the emotional impact of exhibit content on sustainability
- Assessing the on-body exhibit in terms of offering a meaningful learning opportunity, as well as the contribution of the on-body display

Structure

The upcoming chapters of this thesis are discussed here. Section 1 is the current section, and contains a project overview. Here, a better understanding of the museum context is formed, and the objectives of the assignment are described. In Section 2, the previous research is reported. A knowledge foundation

is established through literature work and similar works on projection-based installations. This provided guidelines for how to design an effective museum exhibit for sustainable development that utilizes on-body projections. In Section 3, the development process is reported. This included a more thorough understanding of the requirements of the installation, the ideation of ideas, and the development of the final installation. In Section 4, the exploratory study is reported. Here, the final installation is used to explore the impact of the on-body projections. A qualitative and quantitative user research with actual visitors of the exhibition is conducted, where factors are identified that play a role in the visitors' emotional experience with the on-body projections, and to what extent the exhibit offers a meaningful learning opportunity. The section concludes with the results of the study. This entails a summary of the findings of this thesis, and the meaning of this work for future researchers.

2 The assignment

In this section, the assignment from the museum is discussed, including a description of the exhibition 'One Planet NOW!', the objectives of the exhibit assigned to this thesis, and the initial requirements for the installation. This chapter functions as an overview of the assignment and the requirements from the museum.

2.1 The museum

This thesis is part of a collaborative project for a new exhibition at Museon in The Hague (see figure 1). The investigation of the museum context is based on a description of the museum supervisor, as well as their official website. Museon is an interactive science museum with a focus on broad topics related to humans and the planet. The museum aims to involve the general population with current global challenges through interactive exploration of their exhibitions. Their objective is to increase awareness of the challenges, but also provide a positive outlook on what a sustainable future might look like. Through engaging interactive exhibits, the museum aims to educate visitors on sustainable development.

Figure 1: An overview of 'One Planet' exhibits at Museon (from: www.museon.nl)

The visitors

The main public of the museum consists of families and groups such as school classes and associations. Typically, a significant proportion of the visitors consist of families with young children. However, the museum aims to offer interesting exhibits to all age groups in order to attract a wide range of people. One of the missions of Museon is to facilitate interactions between visitors, as it is believed that collaborative exploration produces more meaningful experiences. The museum does this by offering interactive, game-like exhibits that can generally be interacted with or observed by multiple visitors at the same time. Moreover, in order to keep visitors engaged throughout their discovery process, the museum experiments with exhibits that incorporate novel kinds of interactive technologies.

The 'One Planet NOW' exhibition

In recent years, the museum has shifted their focus more towards educating visitors on sustainable development. In one of their successful permanent exhibitions called 'One Planet', visitors are introduced to the Sustainable Development Goals (SDGs). Drawing upon the success of this exhibition, a follow-up exhibition called 'One Planet NOW' is currently being developed (see figure 2). One Planet NOW' is aimed to focus on positive sustainable changes that are shaping our future. The goal of the exhibition is to foster an inspirational environment where visitors are immersed in the world of promising sustainable innovations of tomorrow. Visitors can experience what the future might look like through interactive hands-on exhibit experiences.

The exhibition will be divided into five themed areas: Food & Drinks, Fashion & Clothing, Building & Living, Sport & Movement, and Humans & Nature. In each area, the visitors are invited to join workshops or other interactive activities, exhibitions and collections. For example, visitors can filter waste water into drinking water, reflect on their own consumptions and redesign clothing pieces from old fabrics in different areas. This way, the exhibition aims to inspire visitors with sustainable developments taking place in the world, and making them feel part of the solution. The opening of the exhibition was launched in February 2022.

Figure 2: The map outline for the One Planet Festival (from: internal source)

2.2 The exhibit

The focus of this thesis project is on the development of an exhibit at the Fashion & Clothing area. The exhibit will resemble a real fashion store in which visitors can try out clothing items. The goal of this exhibit is to introduce visitors to clothing that is made from unconventional sustainable materials and their environmental advantages. This way, visitors can discover sustainable textiles that could potentially replace the more damaging textiles that are currently widely used in fashion.

Objectives

The museum aims to let visitors experience the sustainable fabrics hands-on at the exhibit. The chosen fabrics are not widely used in fashion. This way, the museum hopes to spark visitors' inspiration for what fashion might look like in the future. The exhibit will consists of a clothing rack, a dressing room, and a stage, where visitors can try out clothing made from sustainable fabrics, such as bamboo, eucalyptus, coffee grind, and more. The museum desires to augment the fashion stage with technology as the main experiential part of the exhibit. The goal is that the stage provides a meaningful learning opportunity at the exhibit. Visitors are invited to enter the stage while wearing the sustainable clothes from the racks. On the stage, an installation should be built in which visitors can discover more information about the sustainable materials. Here, the museum suggested to explore the suitability of projection-based technology as a promising novel technology for the exhibit in this project. This set the initial direction for the

thesis project, and sparked inspiration to explore whether this technology would have potential for a museum exhibit on sustainable fabrics. Moreover, a suitable concept, interactions, and content yet had to be decided during this thesis project.

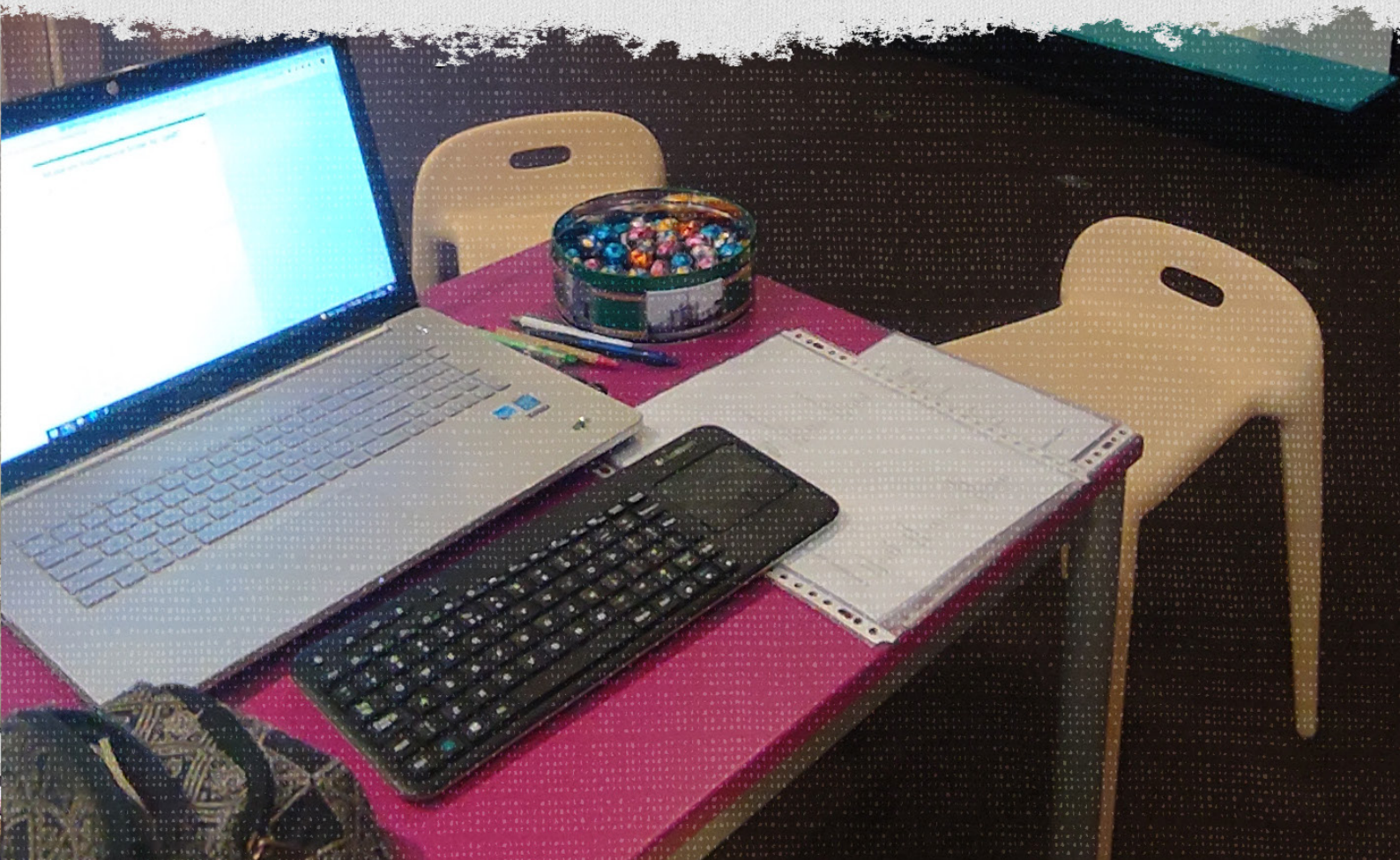
Specifications

The fashion area will be in the backside of the museum in a designated area of around 30 square meters. It consists of a space filled with clothing racks, two fitting rooms and a stage where the visitors can showcase the clothes to themselves and other visitors. Figure 3 shows the designated place for the fashion area. The museum requested that the installation should be novel, embodied and enjoyable for multiple visitors at the same time. The main requirement was that the development of the installation is finished before the opening of the exhibit. Furthermore, it was agreed that the installment of the installation would be supported by experienced employee workers. This way, this work could focus on the design research, software development, and assessment of the novel parts of the installation.

Figure 3: The fashion area for the exhibit (From: author)

Section 2

Research



3. Literature review

This chapter contains a literature research to build a theoretical foundation for engaging visitors in museums through interactive exhibits. In particular, a focus will be on how to better involve visitors in sustainable development. The literature review is divided into three sections. First, the educational strategy to involve museum visitors with sustainable development is reviewed. Second, principles for establishing engaging learning opportunities in museum exhibits are gathered from existing theories on museum learning. Lastly, the rationale and the principles for integrating on-body projection-based technology in museum exhibits are discussed.

3.1 Sustainable education

Global challenges might seem complex in nature and perhaps hard to overcome. Museums can play a role in enhancing awareness through their role as informal learning institutions. In this section, it is researched how different communicative approaches can affect environmental education. Using this knowledge, an educational strategy for the museum exhibit was established.

Sustainable development in fashion

One of the main challenges in climate change is the production of fashion, and the major cause for pollution is the production of fabrics. Textile production is responsible for greenhouse emissions of more than 1.2 billion tons of CO2 equivalent per year (more than all international flights and maritime shipping combined) [10], making fashion one of the main contributors to environmental problems. The most widely used fibers in fashion are made of conventional cotton, and polyester. Both are generally regarded as highly unsustainable. For example, Parthiban et. al. state that conventional cotton requires an extensive use of pesticides and insecticides, toxicity from fertilizers, which creates a loss of biodiversity, pollutes water, and reduces soil fertility [11]. Additionally, cotton requires extensive use of water and land to be produced. Polyester accounts for 77% of the produced synthetic fibers [12]. Oil is mainly used in the production of polyester, a fossil-based resource that is destructive to the planet. Moreover, conventional polyester is plastic, and thus non-biodegradable, which is hazardous to ecosystems in the world.

Due to the clear problems of the widely used fibers, alternative materials are sought with higher sustainable potential. For example, organic materials that require less water, land use, pesticides, insecticides or fertilizers, such as bamboo, hemp, eucalyptus and more [12]. Additionally, sustainable innovators are looking for ways to up-cycle waste, such as recycled PET bottles. Supporting the innovators in their exploration of such fabrics can accelerate progression in a sustainable fashion industry [13]. This can help to improve the environmental impact of novel fabrics within the fashion industry in the longer term. However, most of these fabrics cannot completely solve environmental problems [14]. For example, some of the materials can only partly replace conventional fibers, or might still require chemical processing during production. Nonetheless, it is clear that addressing the issues with fabrics is vital for sustainable progression in the fashion industry. As the production of clothing might be inevitable, innovations in the fabric industry are crucial for progression towards a climate neutral fashion industry.

Education on sustainable development

In the global climate crisis, it is acknowledged that the survival of human societies, as well as biological ecosystems of the planet, are at risk. One of the most important challenges in the coming decades is to develop a sustainable world, while addressing the needs of a growing population. To emphasize the urgent need for sustainable development, the United Nations published the 17 SDGs (see figure 4), a global blueprint for transformative change on urgent environmental challenges throughout the world. As the sustainable crisis exists in all facets of modern society, these goals are established to tackle problems across different disciplines.

Therefore, urgent action is required from society to become more involved in sustainable development. Educating the general public on the importance of a sustainable shift is an essential step towards sustainable transformation. Museums, as informal education institutions, can play a role in increasing public awareness of sustainable development. By involving the general public with sustainable topics, museums can accelerate progress towards a more promising future [15]. Their position in society gives them the ability to introduce people to sustainable topics in their own leisure time. Therefore, there is an opportunity for museums to contribute to a brighter future by actively educating visitors on global challenges.

Figure 4: The 17 Sustainable Development Goals by UN (From: https://sdgs.un.org/goals)

Defining environmental learning - Museums can be promising spaces to educate the general public on the need for sustainable development in all domains of society. Ballantyne and Packer state that through free-choice learning, museums have a unique opportunity to engage visitors with sustainable education [16]. However, they explain that as with regular learning, learning about sustainable issues can be notoriously hard to define in the museum. Visitors enter exhibits with widely differing backgrounds, knowledge, attitudes, and world views, which makes it difficult to define what a meaningful learning about sustainable development entails for each individual. This can be anything from the discovery of an artifact, a conversation initiated by the exhibit, or a recalled memory. As it is hard to capture the vast majority of possible learning outcomes, evaluations on sustainability learning can sometimes be misleading. For example, Falk and Dierking explain that quantitative evaluations might show no learning outcomes, while it actually simply failed to detect implicit learning impact of a museum visit [16]. Therefore, measuring outcomes for environmental learning in museums often relies on the use of qualitative data.

Sustainable attitudes and behavior - Sustainable education is often associated with the aim to alter peoples' attitudes and behavior. To stimulate visitors' involvement in sustainable development, it is beneficial to understand the impact of 'attitudes' on peoples' intention to act. An attitude can be defined as 'the learned tendency to respond to an object in a consistently favorable or unfavorable way' [17]. According to Glasman et. al. [18], when an attitude is consistent, it

can be a predictor for future behavior. Therefore, it is interesting for museums to understand how they can impact favorable attitudes towards a sustainable object. Attitudes consist of three components, an affective component (feelings or emotions towards the attitudinal object), a cognitive component (beliefs or knowledge) and behavioral components (the intention to act) [19].

However, Falk and Dierking state that defining sustainable learning by a shift in attitude or behavior can be problematic [19]. They argue that learning opportunities in isolation, such as an exhibit experience, can be limited in their impact on making a meaningful impact on attitudes or behavior. For example, behavior change caused by an aquarium visit was shown to be short-lived in a study by Adelman et. al. [20]. This is likely because it was not followed by reinforcing learning experiences, which is one of the short-comings of museum visits, according to the researchers. In other situations, attitudes might have shifted, but they do not correspond with intended behavior outcomes. According to Glasman et. al. [18], an attitude has to be consistent, to be a predictor for future behavior. Another well-known problem is the attitude-behavior gap by Carrigan en Attala, which explains that the intention to change behavior does not always correlate to the actual behavior change that is taking place [19]. Additionally, factors such as difficulty or the perceived effort of an action can obstruct the process towards sustainable behavior [21]. Other variables that can hinder the process are lack of self-efficacy (an individual's belief in their own capacities), lack of self-determination (the freedom to act), and lack of locus of control (the perception of personal influence on events) [19]. These factors can make it problematic to use attitudes or behavior change as a learning outcome of museum visits.

Life-long learning experiences - What many researchers disregard, is that museum visits are part of a complex interaction of experiences throughout peoples' life, that incrementally lead to meaningful learning, according to Falk and Dierking [22]. They emphasize that environmental education should be acknowledged as a lifelong process. Informal, free-choice learning in the museum should be understood as one part of the various experiences with sustainability that visitors encounter over their lifetime [23]. Museums are only a minor part of visitors' wide range of past and previous experiences, but in the accumulation and interactions with other learning experiences over a lifetime, exhibits can leave an impact on visitors' world view. Nonetheless, it is hard to measure which museum experiences played an important role in visitors' making of meaning in this learning process. It is therefore notoriously difficult to measure the impact of museum exhibits on visitors' education on sustainable issues [22].

Emotional arousal for environmental learning - However, there is one factor that is consistent benefit for environmental education. Emotional arousal is a

key predictor of effective environmental education, and there are indications that it leads to longer-lasting impact of learning material [16]. In the context of sustainable education, Stapp et. al. [24] argue that to increase peoples' tendency to act more sustainable, their emotional arousal should be evoked in exhibits. For example, visitors of a natural site were more likely to engage in sustainable behavior if they felt emotionally engaged during their visit [16, 25]. Glasman and Albarraci argue that making an emotional impact might be more important than offering insightful information [18]. Moreover, the value of aroused emotions is illustrated by a vivid recall of old memories [27]. Hein adds to this notion that emotional feelings, such as wonder, exploration, and curiosity, should never be underestimated in the impact of learning [26].

A call for future-oriented education

Although raising awareness on environmental problems plays a critical role in creating transformative change, it is reported that people often feel overwhelmed when they are continuously alarmed. For example, disastrous messaging can lead to the phenomenon of disaster fatigue, when the brain subconsciously shuts off when unpleasant information on the topic is repeatedly provided [28]. In effect, avoidance, rejection or denial of the seriousness of environmental problems can occur [29, 30, 31]. In a similar fashion, worrying excessively about environmental problems can lead to a loss of hope [32]. One study shows this might even evoke counteractive behavior, such as moral licensing [33], justifying bad behavior based on previous moral actions, or decision fatigue, becoming overwhelmed from too many or complex decisions. This might lead to the phenomenon that a person is no longer motivated to engage in sustainable behavior.

Optimistic communication - Therefore, some studies suggest that a positive approach as an education strategy could be more effective. A study by Stoknes emphasizes that optimistic communication can be beneficial for environmental involvement [34]. A focus on the positive developments currently rising can increase people's belief that the global challenges can be solved. Alternatively, one study shows that constructive hope is positively related to pro-environmental engagement [32]. Moreover, positive images of development can lead to a higher belief in self efficacy. This future-oriented perspective fuels optimism and a can-do mentality, and can give people the feeling that they can be part of positive change [35]. Considering the above, it can be worthwhile for museums to increase peoples' awareness of the positive change that is happening in the world. A visual comparison of a problem-oriented, and a future-oriented communication approach can be seen in figure 5 and 6, respectively.

Figure 5: Fashion waste piles (From: University of Queensland)

Figure 6: Figure 7 Vegan 'leather' made from pineapples (From: Piñatex)

Promotion of sustainable innovations - Moreover, the adoption of sustainable innovations is reviewed. One study shows that acceptance towards sustainable products is highly influenced by affective factors, as well as their perceived innovative value [36]. This is particularly the case when sustainable products are novel and non-traditional for people, such as insects as food. For example, the study found that the perception of sustainable food is highly mediated by the perceived innovative value of the product. When people perceive a product as highly innovative, they are more likely to accept the product, even when they have a negative association with the product. Thus, the perceived innovative value of a product can support consumer acceptance of novel products. However, more importantly, the study shows that affective emotions, both positive and negative,

such as feelings of disgust, or ambivalent feelings, have the most significant influence on acceptance of innovative products.

3.2 Interactive learning in museums

A returning challenge for museums is how they can engage their visitors and provide meaningful learning opportunities. Foremost, it is important to learn the principles of designing effective museum exhibits. The principles for museum leaning can then be applied to the exhibit about sustainable development. The following paragraphs will discuss the role of modern museums and their visitors, and the principles for reaching immersive learning experiences in more detail.

The modern role of museums

In earlier decades, museums' objective was to collect, showcase and store artifacts of cultural and historical heritage. However, a significant shift in approach has taken place in recent years, and museums are increasingly taking on a more active role in society [37], where they are 'challenging and impacting how visitors think, feel and act through thoughtful exhibitions' [2]. Ballantyne and Packer state that the aim for modern museums is to 'encourage curiosity and exploration, change attitudes, evoke feelings, help develop a sense of personal, cultural and community identity, and make decisions about moral and ethical issues' [16]. When exhibitions are designed thoughtfully, museums can have a long-term impact on visitors' learning outcomes [38], and can even help them find meaning in cultural, historical, environmental or other aspects of life [37]. One of the major influences in the museum learning in the last decades is the 'sensory and emotional turn' [39]. Csikszentmihalyi points out that it is no longer merely the intellectual that matters during a museum visit, but the emotional and sensory realms of the visitor experience should be considered as well [36]. Particularly, there is a re-discovery of the importance of object-handling on visitor experiences, according to Peng [39]. Hein adds to this that a combination of hands-on and minds-on components is most effective for museum exhibits [26] (see figure 7)

Figure 7: Visitors exploring a hands-on and minds-on exhibit (Photo from: Bart Nijs)

Museum visitors

Visitor groups - Since museums are informal institutions for the general public, they generally attract a wide range of people. One of the ways to understand what engages different visitors is to look at their characteristics, as these can function as an indicator of visitor needs and desires. During museum visits, most visitors aim to satisfy their curiosity and desire for interesting experiences, and look for an engaging day out with their social group [40]. In general, visitors to informal science institutions tend to come in groups, consisting of family, friends and relatives [37]. Their visit to the museum is highly social, which should be addressed in the museum exhibition. This means that exhibits should work well with multiple users and enable interactions between visitors [41, 42].

Age differences - Moreover, most groups visit museum sites with their own or their relatives' children. Children tend to be occupied with their own experiences, whereas parents' satisfaction with a museum visit is more dependent on the children's experience [43]. It should be noted that visitors of different ages can have different education levels. Sandifer states that to account for different intellectual levels between age groups, information in museums should have multiple layers of complexity [44]. Borun identified principles for exhibits that increase engagement of visitor groups: enable clustering around the exhibit, enable control of the exhibit by multiple visitors, and enable complex outcomes for group discussions [45]. The paper states that several principles can help to minimize distractions for different visitor groups. These should be considered in particular: 1) the accessibility: appropriate for all ages, 2) the multi modality: suitable for different learning styles and levels of knowledge, 3) the readability: the text should be simple and digestible, and 4) the relevance: the availability of

links to visitors' personal backgrounds.

Visitor needs - Additionally, analyzing visitor behavior can lead to a better understanding of visitor needs. It is important to consider that visitors have a limited resource of attention that they can spend during their museum visit. In the abundance of information in museums, visitors will have to choose a selective amount of exhibits to attend. A study from Serrell illustrates this with the finding that on average, visitors of a science museum only looked at between 20% and 40% of the exhibits [46]. According to an analysis of 33 exhibits at the Reuben Fleet Science Center, a science museum and planetarium in San Diego, the holding time, or time that visitors spend at each exhibit, summed up to a total of 1.5 minutes [44]. This implies that science museums have limited influence in the decisions that visitors make throughout their visit. Because of the extensive freedom of choice in museums, Csikszentmihalyi suggests that it is particularly important to stimulate the visitors' intrinsic motivation to learn more about the exhibits [36].

Stimulating intrinsic motivation

Free-choice learning - Learning in museums is mainly based on the choices visitors make throughout their visit. Museums are places for informal learning, meaning that the visitor obtains new knowledge without a predefined outcome [26, 47, 48]. This is closely linked to theories for free-choice learning, meaning that visitors learn in non-sequential order, at their own pace, by their own choice [16, 49]. The exhibits ultimately give visitors the freedom of deciding what to try, how much time to spend per exhibit, and which series of actions to do [50]. Therefore, in order to establish a rewarding learning experience, it is essential for museums to know what drives the visitors' intrinsic motivation to interact with exhibits. To better understand intrinsic motivation to learn, a well-known framework by Csikszentmihalyi for museum learning is reviewed [36]. The framework forms a fundamental guideline for designing immersive learning opportunities in exhibits. Therefore, it is used as a guideline for the further exploration of designing effective museum exhibits. A reference to the full framework is presented in figure 8.

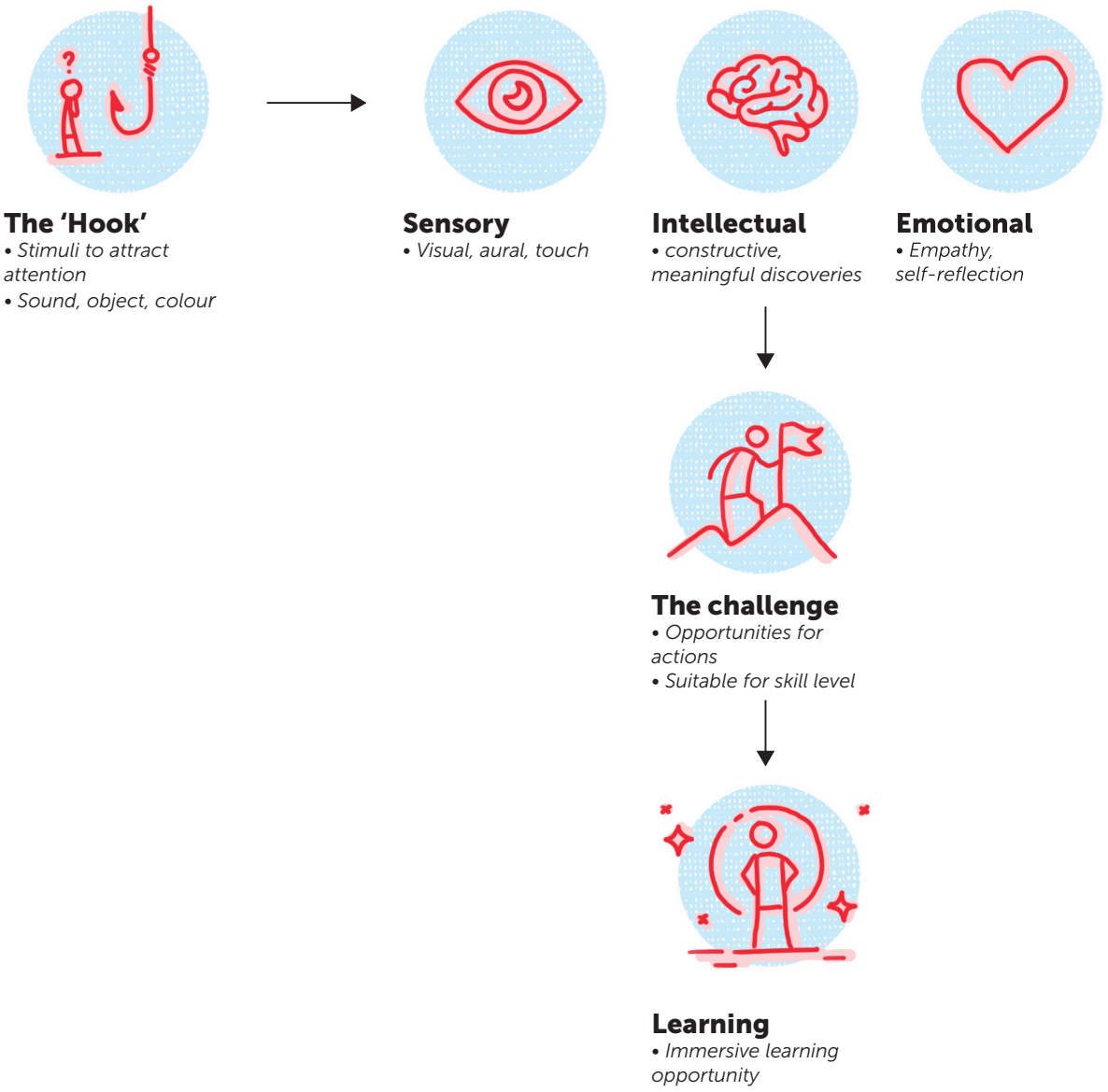


Figure 8: Model is based on principles for museum learning through intrinsic motivation

Museum learning - According to the framework, there should be a 'hook' to initially attract visitors, which is an element that sparks visitors' curiosity towards an exhibition. In other studies, this is known as the attractor [51, 52]. The hook can be a remarkable element such as a striking sound or an unusual image, which leaves the visitor wanting to learn more. Following this, the visitor should find personal interest in the content of the exhibition. This can be done by showing the relevance of the information to their personal life's, or showing how it is linked to a bigger picture. Additionally, the ability of the exhibit to make a subject come to life can increase personal relevance [44]. After the initial attraction, the exhibition should incorporate opportunities for involvement. Other studies refer to these features as the sustainers [51] or exhibits' holding power [52]. This is focused on sufficient levels of sensory, intellectual and emotional stimuli in an exhibition.

Although intellectual engagement is the most conventional in museum exhibits, lately the importance of sensory and emotional engagement has been getting more recognition in research [39]. Next to that, it is recognized that social interactions with other visitors can increase visitor involvement. Malone and Lepper found that social motivators, such as competition, cooperation and recognition of other participants, can positively affect peoples' intrinsic motivation during a learning experience [53]. Finally, the exhibition should consist of a challenge that has clear instructions on how to reach the desired goal, should be well-balanced in terms of its perceived difficulty and visitors' skill levels. If these factors are considered, the exhibition sets the right circumstances for the experience of flow [54]. Ultimately, the aim of the framework by Csikszentmihalyi is to give visitors a sense of immersion in the exhibit experience [36]. The following paragraphs will elaborate more on the importance of fostering immersive learning experiences. Moreover, the conditions of flow are explained in more detail.

Levels of immersion - Csikszentmihalyi links immersion at a museum exhibit to the experience of flow, which he describes as 'a state of mind that is spontaneous, almost automatic, like the flow of a strong current' [54]. This is an immersive state where the body and mind become completely involved in an activity, which is an optimal form of experience that is joyful and intrinsically rewarding. This makes the feeling of becoming absorbed by an activity or exhibit highly enjoyable. Such immersive experiences likely stimulate visitors to become stronger involved in the exhibit content, which in turn increases the learning impact of museum exhibits. According to Brown and Cairn, three levels of immersion can be distinguished: 1) engagement: the investment of time, effort and attention, 2) engrossment: where emotions are directly affected, and 3) total immersion: where the experience is all that matters [55]. An immersive experience is generally considered to be an intense and highly pleasurable state. In order to support learning objectives, at least the stage of engagement should be reached. However, as levels of immersion increase, it becomes more likely that the visitor finds the experience pleasurable and memorable. Therefore, museums should aim to reach high levels of immersion in their exhibits.

The principles of the flow state - Csikszentmihalyi explains that principles for the 'flow state' should be considered when aiming to reach optimal immersive states in museum exhibits [36]. This is an intrinsically rewarding and satisfying state of mental and physical stimulation on the right level of challenge. For such a level of immersion to occur, distractions should be minimized and sufficient levels of challenge for all visitors should be provided. Additionally, it is important to give the visitor clear and manageable goals throughout the exhibit design, and receive immediate feedback [36]. This way, the visitor is always aware of how to proceed

with the challenge. Moreover, it is considered beneficial for engagement to ask the visitor to commit themselves to the exhibit, to be reactive, make guesses, and reflect. Next, it should be possible for visitors with a varying set of skills to take up the challenge, and the difficulty of the challenge should be adapted accordingly. In order to minimize distractions from usability issues, it is important to consider affordances in interactive installations [56]. In other words, visitors should have a clear action perspective on how to handle objects and what actions they can expect to take [57]. As mentioned, Csikszentmihalyi states that a combination of sensory, intellectual and emotional attributes should be included to increase the immersive qualities of an exhibit [36]. This in turn, will keep visitors intrinsically rewarded to engage with the exhibit, leading to better learning opportunities. However, the framework provides little guidelines for integrating the three attributes effectively. Therefore, the next paragraphs will review in more depth how museums can implement sensory, intellectual and emotional attributes in their exhibits to more likely foster immersive learning experiences.

Intellectual attributes

The importance of stimulating the mind in museum exhibits can be explained by our natural drive to learn. According to Csikszentmihalyi, humans have a natural desire to learn, and we find pleasure in the process of acquiring new information [36]. Intellectual stimulation was one of the earliest goals of museum exhibits, and it is still relevant to this day. Hein argues that in order to foster truly meaningful experiences, exhibitions should contain minds-on elements that mentally engage visitors with the exhibition experience [26].

Learning in the museum - It is important to understand what is meant by learning in museum settings. Definitions for learning can vary in different contexts. Cohen-Jones et. al. [58], and Falk and Dierking [49] argue that the conventional definition for learning as a retention of facts is too narrow for learning in museums. According to them, learning entails all aspects of a novel encounter. For example, they explain that part of the learning process is discovering how a particular artifact looks and feels, or learning how to handle an instrument. Although these situations do not produce a retention of facts, they are still meaningful experiences that can help an individual grow. Additionally, shifts in attitudes, beliefs or values, can be part of a visitors' learning experience. From this perspective, learning entails every meaningful experience that helps visitors make sense of the world around them.

The constructive learning model - This is in line with Hein's notion of constructive learning, which focuses on the learning process taking place inside each individual, making meaning through their own interpretations [26]. In recent

years, a growing number of exhibitions in museums incorporate elements for the constructivist model [40]. The study of Gruninger et al. shows the effectiveness of constructive learning, explaining that in their experiment, visitors who constructed information through their own discovery tend to process information on a deeper level, than the ones who received readily presented information [59]. In this learning model, visitors are encouraged to form knowledge through their own subjective experiences and personal background. To incorporate this model, the visitor should be invited to discover material and reflect on it in their own way. This can be done by providing alternative stories of a concept or theory and actively promoting visitors to reflect on the subject.

Learning together - As is described previously, museum visits are highly social activities [41, 42]. Therefore, studies point out that exhibits should provide points for social interactions. A theory on cooperative learning by Johnson supports the benefits of working together during a learning process [60]. The study focuses on strengthening cooperation between students in a classroom. However, positive interdependence, a principle at the heart of cooperative learning, can also be applied to a museum context. This is the perception that you depend on each other to succeed in a certain task. Methods to increase positive interdependence are: 1) giving members of the group joint rewards, 2) providing members partial information that can be combined, 3) giving each member a separate role. These methods can strengthen the feeling of social interdependence, and in turn help to maximize learning outcomes in groups.

Emotional attributes

An important aspect to consider for effective exhibitions is the visitors' emotional experience. Emotions are psychological states that are often categorized as separate entities, such as with the six core emotions by Ekman that include happiness, sadness, anger, disgust, fear and surprise [61]. However, other studies suggest a representation of emotions by their degree of arousal and valence is more effective [62]. There is no consensus in science on how to define emotions, as they are too complex to be defined in exact terms. Nonetheless, there is a growing recognition for the influence of emotions on visitor experiences in museums [63].

Enhancing emotional engagement - According to May, affective engagement has a positive effect on multiple mental processes, such as motivation, memory, decision making, reasoning, and creativity [64]. Consciously or unconsciously, affective states motivate our actions, drive our choices and make experiences memorable [49]. This makes them a key aspect of learning. Moreover, museums should not only aim to evoke basic emotions, but more complex emotional states

as well, such as curiosity, fascination, suspense and surprise [64, 40]. One of the most crucial affective states for learning in museums is curiosity [36]. Zheng argues that the sensation of curiosity comes from surprise, one of the basic human emotions [42].

Enhancing curiosity - It is clear that curiosity is an important aspect of emotional learning in museums. According to Litman, curiosity is inherently part of our brains [65]. As a species, we have an instinctive tendency to explore novel stimuli, and resolving this curiosity is a highly rewarding and pleasurable experience. By providing visitors an opportunity to arouse complex emotions like curiosity, the discovery experience becomes more pleasurable. Moreover, curiosity is one of the key influencers of learning through intrinsic motivation, according to Csikszentmihalyi [36]. Thus, provoking curiosity can help to keep visitors motivated in their discovery of sustainable fabrics. A straightforward way to activate curiosity is by presenting visitors with novel and unexplained stimuli, such as an unexpected sound, a strange object or a mysterious sign [36]. To sustain curiosity throughout the interaction, an effective strategy is to provide information incrementally, according to Berlyne [66]. By not immediately providing the complete narrative, visitors get pleasantly aroused when they find the missing pieces of information. The effectiveness of this principle can be seen by the popularity of puzzles and mystery games like scavenger hunts, especially among children from seven years old and above [67].

Different forms of curiosity - Museum installations could also engage their users intrinsically through curiosity. Another study on game design distinguishes different kinds of curiosity [68], such as perceptual, manipulatory, ambiguous, conceptual, and adjustive-reactive curiosity. Perceptual curiosity is the positive reaction to the discovery of new sensory experiences or the discovery of one's surroundings. This can be indulged by allowing visitors to explore an area, retrieve sensory stimuli, or collecting hidden items. Manipulatory curiosity is the urge to understand the physical nature of an object. In museum exhibits, this results in the pleasurable behavior of touching and interacting with an object to observe how it responds. Ambiguous curiosity is aroused when a person tries to make sense of a complex stimulus that is ambiguous in nature, such as when it is unclear what effect a certain action or item leads to. Conceptual curiosity is the most common understanding of curiosity, and it entails the drive to find out the 'why' something behaves in a certain way. This is often indulged when people can find answers about a specific question or when they find the gaps of a causal story. Adjustive-reactive curiosity is the type of curiosity that does not look for novel stimuli, but rather tends to confirm expectations of existing mental concepts. For example, people tend to find pleasure in interacting with objects in common ways, like

opening and closing a box. These different forms of curiosity can be activated by thoughtful design of the exhibit.

Sensory attributes

Similar to emotions, there has been an increased acknowledgment of the importance of sensory stimuli in an exhibition. Particularly, the stimulation of multiple senses, also known as multi sensory experiences, has been getting more attention [69, 63, 70, 4, 71]. Museums are beginning to explore how the sensory elements of historical or cultural objects can enrich visitor experiences. According to Weng, multi sensory exhibits hold multiple benefits to museums as they increase the attracting and holding power of the exhibit, provide more memorable experiences and add emotional value [70].

Multi sensory approach - Although elements that stimulate the visual and auditory senses are most widely integrated in multi sensory museum interactives, the positive effects of including the senses of touch, smell and even taste are increasingly being reported by researchers [69, 4, 71]. Moreover, multi sensory approaches can positively influence the level of immersion that visitors experience. According to Falk, museums should strive to become places where all the senses are activated [63]. They should become "a multi sensory space-time that breathes, resonates, and vibrates (p. 33)", which helps to absorb visitors in their own imagination. Heim advises to address at least two senses in an experience designed to increase immersion [72]. The decision for which senses to include is context-specific, and should be determined by the objectives of the exhibit. Greppi explains that the aspects of sonorisation are in particular crucial for effective exhibits [63]. He reasons that sounds are crucial to exhibits, as they have the ability to induce emotions in an immediate way. According to the researcher, sound atmospheres should induce emotions that fit the narrative of the exhibit.

Contrasting elements - Moreover, Owen suggests that museums can make use of dramatic elements to induce emotions. To do so, exhibit designers must consider the importance of contrast [63]. For example, loud sounds can be used to induce higher levels of arousal. However, when every sound element is loud, the impact of the overall effect decreases. Therefore, the impact of a central element can be increased by surrounding it with contrasting lower-energy elements. For example, a light spot has more impact in a dark environment (see figure 9). Museums should strive for a right balance between lights and shadows, silence and sounds, and solids and voids.

Figure 9: Dramatic lightning contrasts at the Natural History Museum of Florence (photo by Lorenzo Greppi)

Hands-on and bodily experiences - One of the most prominent shifts in the sensory field is the rise of bodily experiences, more specifically hands-on experiences and the handling of museum objects [3, 39, 26, 44, 73]. The conception is that this allows visitors to better grasp the essence of the exhibition. The integration of touch is now so common that visitors of a museum have an increasing expectation to be involved in exhibition experiences, as is illustrated with the notion of visitors becoming 'visit-actors' [73]. Visitors are no longer passive observers, but want to be active participants of the interactive storyline. Moreover, the rise of interactivity in exhibitions can be a stimulant for talking, communication and cooperation between visitors [49]. Hands-on exhibits are most effective for visitors of all age-groups, as an analysis on visitor behavior at museum exhibits shows [74]. The results showed that elderly tend to ignore screen-only exhibitions, while children tend to walk past standalone physical artifacts. Interestingly, interactive exhibitions attracted visitors of all age groups and kept them engaged the longest. Falk and Dierking [49], and Schwan et. al. [40] show that interactive exhibitions can positively shift visitors' perspective on the value of their museum visit. Hence, museums can benefit greatly from incorporating interactive exhibits with a focus on the visitors' sensory experiences.

3.3 On-body projections in the museum

Interactive technologies in museums

Museums are increasingly looking for ways to implement interactive technologies into their exhibitions. In this chapter, the role of technology in museum exhibitions is researched. Next to that, the challenges museums face in the implementation of technology, as well as the potential for on-body projection-based technology to overcome these challenges, are reviewed. As there is little research on the use of projections onto the body, this chapter will review projection-based installations in general. Finally, how to evaluate the effect of interactive technology on visitor engagement is reviewed.

Immersive experiences through technology - Multiple studies show the positive effect of the increased use of interactive technologies in museums [39, 42]. Interactive technologies can be highly effective in enhancing the visitor experience in museums [38, 73], and can increase the time that an exhibition holds the visitors' attention [44]. Additionally, these technologies can be of great use for fulfilling expectations of modern museum visitors to get involved in hands-on experiences [75]. Moreover, interactive technologies can be utilized for creating immersive and engaging visitor experiences and offer more sensory-rich and interactive experiences, since key characteristics of new technologies in museums are that they are multi-user, immersive and multi sensory [39].

Risk of distraction - In order to maximize the impact of interactive exhibits, it is important to understand how the effectiveness of interactive technologies can be increased. As Campos et. al. points out, one of the most important aspects of technology is that it does not distract from the learning goals of the exhibit [56]. Moreover, Greppi states that technology should be seamlessly integrated in the exhibits' scenography [63]. Zheng points out that technology should not be too complex, otherwise the application might overwhelm visitors [42]. This is particularly an important aspect to consider for novel technologies that visitors are not yet familiar with. Technology should be a means to an end, staying in the background while the experience is at the forefront of the exhibit. One way to achieve this, is to establish intuitive interactions between the visitor and the exhibit, for example with the use of bodily interactions [69, 76]. This way, the technology responds intuitively to the visitors' gestures or movements, without much need for explanation.

Unreachable image space - Despite the growing popularity of new technologies, it is regularly reported that museums struggle to integrate technology with their artifacts seamlessly [56]. Moreover, multiple researchers have pointed out their concern about technology drawing visitors' attention away from the real environment [69, 77, 78, 79, 80, 81, 82]. For example, many interactive technologies in museums heavily rely on the use of screens. This can result in

visitors' focus being heavily drawn to screens, removing their attention from the artifacts in front of them [78, 79]. Another growing trend in museums is the use of technology from the mixed-reality continuum [83], such as virtual reality or augmented reality applications. These applications rely on use of a smartphone or head-mounted displays. In either case, the visitors' senses and reality are obstructed and augmented by an intermediate layer. Rowe's quote explains the risk of technology as intermediate layers well: "It is a framed view in another, which creates an unreachable image space that is detached from reality. Likening to a view through a window, a disembodied, distance and displaced relationship with the viewer is created" (p. 156) [84].

Obstructing the real environment - The obstruction of the museum environment can be disadvantageous, since the sense of being in a museum space can offer vivid learning experiences [85]. Moreover, such technologies can isolate visitors and might limit opportunities for social interactions between visitors [4]. Another study warns that new technologies in museums tend to compete with the original objects, which can be destructive to the overall experience. As illustrated by VomLehn et al., visitors may spend "*more time with the system than with the original object, resulting in a displacement of the object by the technology used*" (p. 154) [12]. When visitors become more drawn to the technology, the learning goals of an exhibit might not be met successfully [56]. For example, in this scenario the visitor might spend less time learning about the way an artifact feels, how it should be handled, or how it behaves. It is clear that museums should be cautious of displaying information though intermediate layers.

Projection-based technology in the museum

A seamless blend - Due to the challenges pointed out above, several researchers have voiced the importance of museum exhibits in which digital and physical tools are harmonized [69, 86]. Therefore, researchers are now exploring promising technologies that are more naturally merged with reality [87, 88, 89]. This is achieved by looking at forms of immersive technologies that are more embodied in the actual space. This way, researchers aim to create engaging visitor experiences within the physical environment [69]. A promising direction is the use of projection-based technologies, which entails technologies that overlay virtual information onto the physical space through use of projectors [88, 84, 90, 91]. In projection installations, the virtual and the real are blended seamlessly, establishing a more natural interaction between both worlds [4].

Projection-based technology - In museum research, there is a wide range of projection installations with different use applications and technical settings. Projection-based technology has previously been used in projects such as '3D

projection-mapping', 'Spatial Augmented Reality' [90], or 'Interactive immersive multimedia walls' [76]. Projection installations are rarely solely based on projections onto physical objects. Rather, they are often supported by other multimedia features. For example, sound is often used as an addition to visual effects, to amplify the overall experience. In the paper by Dalsgaard, projections onto a rune stone visualize the stone breaking, and cracking sounds are played simultaneously [90]. Moreover, text elements and voice-overs are used in projection installations for exhibits [92]. This can be used to convey information, rather than merely presenting visual effects. By combining projection-based visuals with other sensory features, truly immersive experiences can be established.

Potential of projection installations - Projection-based installations have multiple benefits for educational purposes. Dalsgaard found that projection-based installations can be effective in enhancing visitors' awareness of a physical object onto which virtual content is displayed [93]. For example, the technique can be great for storytelling, or showing the object from a different perspective. Moreover, studies have found that projections onto objects can lead to a higher sense of immediacy and different quality of presence than content displayed on conventional devices, like screen or head worn displays [5]. Another benefit is that projected installations are by default visible for all visitors, enabling a 'shared experience' [6]. This provides more opportunities for social interactions. Moreover, projections onto physical spaces can provide a more natural and intuitive way to engage with interactive technology [84]. Finally, a paper outside of museum research produced indications that projection-based technologies can give people a deep sense of unity with content displayed onto physical objects [7] or onto a body [8]. The study by Morikubo et. al. focused on advancing object projection-mapping techniques, but noticed that the projections managed to enhance their participants' emotional connection with the virtually enhanced object. Hoang et. al. explored the use of the body as a canvas in a physiotherapy education class, and noted that the participants felt closer connected to the virtual content. Moreover, they state that this sense of unity is felt not only by the target person, but by observing people as well. This was possible as all participants in the room shared a similar visual experience.

Content for projection-based exhibits

Types of content - Falck and Halskov established a framework that can help designers in the realization of projection installations [92]. In the following paragraphs, a summary is given of their design considerations. These can be helpful in understanding how to give shape to a projection project. To integrate projections into an exhibit, it is essential to collect content. Falck and Halskov

distinguish five forms of content that are used in projection installations: film, animation, still photos, graphics, and text [92]. Depending on the type of content, different effects can be realized. Moreover, there are different kinds of content complexity that should be balanced with the complexity of the object shape. More complex content is more suitable for relatively flat shapes, and simpler content can more effectively be projected onto more complex shapes. For example, film or animation with many informative details would work better on relatively simple geometric shapes, whereas more abstract graphic effects can be used on more complex shapes, such as statues, buildings, or utensils. However, Falck and Halskov state that with careful design some types of content, such as animation and text, can be projected on any type of shape with good results.

The content and the object - Projection installations generally are used to deploy a certain experience, or to tell an educational story. Falck and Halskov explain that the connection between the content and physical object is a unique challenge for development of projection installations [92]. To distinguish how content and physical objects might relate to one another, they reviewed several projection-based cases in museums. Generally, they found that the digital content is deeply rooted in the physical object. For ancient artifacts, like a statue or a rune stone, the digital content can easily be linked to their historical stories. However, they also found cases in which there is a weaker relation between the object and the content. For example, a case was illustrated in which a monster with tentacles was projected onto a public building.

Technical considerations for projection-based installations

Realistic projections - According to Dalsgaard, due to the challenges that designers face with the implementation of projection-based installations, most research has been executed in controlled lab settings [90]. One paper by Roo and Hatchet discusses that dynamic projection-mapping holds great potential for user interactions, but the generated illusions can be fragile [94]. To overcome this, the geometry, color, position, and color of the object should be considered for accurate projections. Moreover, Lee et. al. [89] states that highly controlled lightning is important for effective projections, since lightning conditions determine the appearance of the projection. These factors can help to increase the realism and impact of the projected content.

Dynamic projection-mapping - Moreover, projection-mapping on dynamic and moving objects remains highly challenging. Nonetheless, some studies are exploring how to project virtual content onto dynamic user bodies, for example. The complexity of the technology for projection onto objects varies. For example,

for static objects, a virtual model of the actual object is needed, onto which the projected content can be displayed without tracking. On the other hand, dynamic objects generally make use of motion tracking of an object, using three-dimensional matrix transformations to correctly place the projections onto the dynamic surface. Moreover, for projections onto people, body tracking or motion tracking is generally used. For example, this has been done for projecting virtual content onto dance performances [93]. To decrease latency of the projections, pose estimation techniques have been used in an artistic installation [95].

Interactions in projection-based installations

Bodily interactions - Additionally, it is interesting to explore what kind of interactions are suitable for projection-based installations. Projection-based installations that involve some kind of interaction, and allow visitors to manipulate the scene, generally cause more enjoyment, engagement and interest [96]. Several researchers suggest that natural, continuous interactions should be strived for in projection-based installations. Snibbe and Raffle argue that developers should avoid using the visitors' body as an extended pointer that activates buttons or widgets [76]. Instead, researchers suggest to use gestural and bodily interactions for projection-based interactions [94, 96, 97]. However, Roo and Hatchet note that the scale and context of the projection determines which kind of bodily interaction is most suitable [94]. For example, it is suggested to use whole-body interactions for room-scale projections, whereas hand gestures might be more suitable for projections onto smaller objects.

3.4 Evaluating learning at the exhibit

In the previous section, clear indications were identified that projections can offer a sense of unity between virtual content and the object onto which the projections are displayed. In particular, it is promising to explore how on-body projections might affect the visitors' emotional connection with the exhibit content. This could in turn increase the effectiveness of learning on sustainable development. However, after gathering knowledge from research, the challenge remains to evaluate whether the objectives of the exhibit have been met.

Instruments for user research

It can be valuable to gather insights about visitors behavior during the exhibit interaction, or their attitude after the encounter. These insights can be used for progression towards more meaningful learning opportunities during museum visits. According to Damala, assessing the impact of immersive and embodied technologies is one of the hardest challenges that museums face [4]. For example, interactive

exhibits often consist of several interactive and multimedia components, and their combination determines the impact of the exhibit. It can be time-consuming to measure the contribution that each design element makes separately. Moreover, interactive exhibits are often assessed real-time in the actual environment of the museum, rather than in a laboratory, which makes evaluation of single variables challenging.

As there were no methods found to evaluate the impact of on-body projection-based technology, it was reviewed how interactive exhibits are generally evaluated in research. Widely used evaluation methods for interactive exhibits include interviews and analysis of visitor interactions [39]. In quantitative analysis, quantitative metrics such as minutes spent at the exhibit, percentage of people attracted by the exhibit have been used by previous studies [40]. This can be analyzed with the use of recordings of visitor behavior, or with live observations by researchers. It can provide indications for how engaged visitors are with the exhibit. Furthermore, researchers tend to include open-ended questions in interviews to account for unexpected findings, such as usability issues or subjective experiences [56].

Measuring exhibit impact

Emotional connection with exhibit content - Researchers have suggested that on-body projections can increase peoples' sense of unity with projected virtual content [7, 8]. However, these findings were unexpected 'by-products' from the actual research experiments. Consequently, no in-depth investigations have yet been conducted on the extent of this emotional effect or its explanation. Similarly, no measurement scales have yet been employed for such a research purpose. Therefore, measurement scales from related fields have been reviewed. One of the most promising scales that is related to a sense of emotional connection is the psychological 'Inclusion of Other in the Self (IOS)' scale by Aron et. al [98]. This is a single-item scale measuring how close someone feels with another entity, which can be anything from another person, a group, an object or even an abstract idea. The scale does not rely on verbal expressions, as people can visually highlight their relationship towards the 'other' with the use of gradually overlapping circles (see figure 10). Therefore, it provides an intuitive way for people to express their sense of connection with another entity [98].

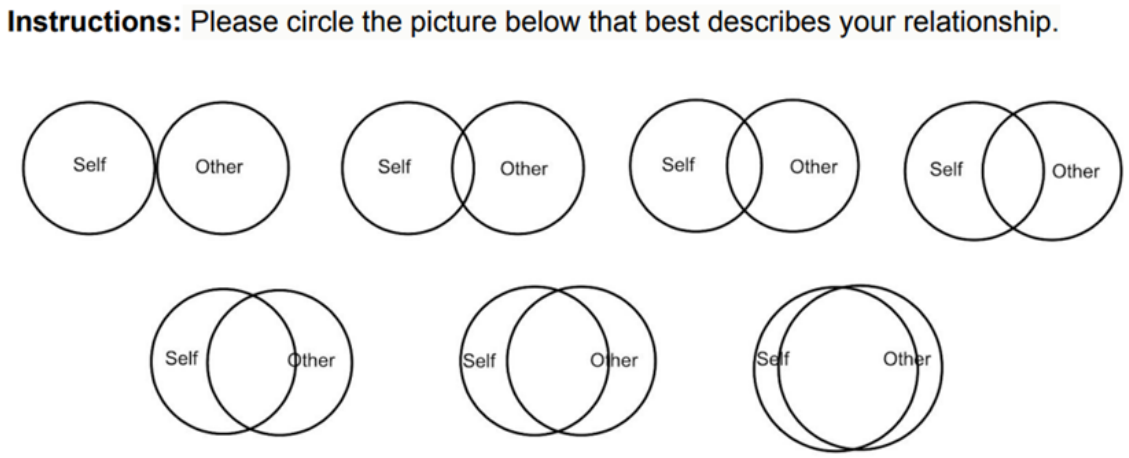


Figure 10: Overlapping circles, the Inclusion of Other in Self Scale

Measuring learning opportunities - There are many examples to measure learning opportunities in exhibits through user studies. For example, there are measurement scales dedicated to measuring levels for immersion [14, 15], or measuring the engagement of visitors [99]. There is flow [54], which has been measured in many different user research contexts [19, 24, 16]. However, none of these measures are specifically tailored to the characteristics of museum exhibits, or only focus on engagement levels. To be able to measure the most important components of an effective learning opportunity in museums quantitatively, the Museum Experience Scale (MES), developed by Othman et. al., was reviewed (see figure 11) [9]. Originally, the MES scale was developed to assess the impact of audio guides on the visitor experience in museums. Although this is different from the objectives of this study, it is the only scale to measure visitor experiences in museums. Additionally, it could be considered most closely related to the principles for immersive learning experiences in Csikszentmihalyi's framework [36]. The scale captures most of the relevant internal motivators for a meaningful learning opportunity: engagement, knowledge/learning, meaningful experiences, and an emotional connection with the exhibit.

Also, as pointed out by Falk and Dierking, emotional arousal is one of the most consistent predictors for effective sustainable education in museums [22], but traditional evaluation methods generally fall short in measuring the emotional aspect of learning experiences in the museum [39]. The MES is one of the only scales that includes emotions in its evaluation of effective learning opportunities. The scale consists of 5 statements per variable, where each statement is answered on a 5-point Likert scale. The scale has successfully been used in a study with 255 participants from diverse backgrounds, to ensure high robustness. There are

5 statements per variable that form a combined average for each variable. This makes the MES scale suitable for statistical analysis, where the data can be treated as an interval type.

Table 1. The 4 components of the Museum Experience Scale (MES) and their factor loadings

Engagement		**Knowledge/Learning**	
I enjoyed visiting the exhibition	0.69	The information provided about the exhibits was clear	0.64
I felt engaged with the exhibition	0.69	I could make sense of most of the things and saw and did at the exhibition	0.57
My visit to the exhibition was very interesting	0.68	I liked graphics associated with the exhibition	0.52
I felt I was experiencing the exhibition, rather than just visiting it	0.65	My visit enriched my knowledge and understanding about specific exhibits	0.52
My visit to the exhibition was inspiring	0.56	I discovered new information from the exhibits	0.43
Meaningful Experience		**Emotional Connection**	
During my visit I was able to reflect on the significance of the exhibits and their meaning	0.74	The exhibition enabled me to reminisce about my past	0.55
During my visit, I put a lot of effort into thinking about the exhibition	0.53	My sense of being in the exhibition was stronger than my sense of being in the real world (reversed relationship)	0.52
Seeing rare exhibits gave me a sense of wonder about the exhibition	0.50	I was overwhelmed with the aesthetic/beauty aspect of the exhibits	0.47
After visiting the exhibition, I was still interested to know more about the topic of the exhibition	0.43	I wanted to own exhibits like those that I saw in the exhibition	0.45
Seeing real exhibits of importance was most satisfying aspect of my visit to the exhibition	0.43	I felt connected with the exhibits	0.45

Figure 11: The statements for the four variables in the MES scale

3.5 Literature review: conclusion & discussion

Sustainable education

In this chapter, the need for environmental education is discussed. Moreover, strategies for enabling effective learning opportunities in sustainable development are reviewed. The findings are summarized in this section.

1. "What are guidelines for effective learning about sustainable development through an on-body projection exhibit?"

Life-long learning - In this chapter, it was found that raising awareness about global challenges is vital for a transition towards a sustainable society [13]. Informal educational institutions, such as museums, can play a key role in involving the general public with sustainable topics [15]. However, involvement with sustainable issues does not happen instantly. According to Falk and Dierking, learning about environmental issues is an ongoing process, that happens in the accumulation of experiences throughout peoples' lives [22]. As a museum visit is only a part of the incremental growth of ideas [23], it might be unrealistic to expect long-term changes in attitudes or behavior due to a single museum visit. Instead, they state that in future museum education, it should be acknowledged that learning about sustainable development is a lifelong, non-linear process [22]. In that process, every experience shapes future experiences, but it is hard to know to which ones ultimately become meaningful. A person might learn something entirely new in a second visit at the same exhibition. One seemingly unimportant encounter with an object might have actually contributed to the initiation of a meaningful conversation later that week. On the other hand, a meaningful thought might fade away over time, when no reinforcing experiences are followed-up.

Emotional arousal - Thus, how a museum visit has ultimately impacted visitors' lives, can be difficult to capture in the data. It might seem that there are no ways for museums to produce the exact learning goals as intended, and that it is largely due to faith whether and what visitors learn or not. However, one of the most consistent components for effective environmental education, as argued in multiple studies, is the arousal of emotions [18, 24, 16, 27, 22]. In fact, emotional stimulation, such as evoking feelings of self-reflection or empathy [25], is a consistent predictor for effective learning about sustainable challenges [16]. Moreover, it can lead to longer-lasting impact of the learning material, and can increase peoples' intentions to show more sustainable behavior [24, 16]. These studies illustrate the importance of stimulating an emotional response at the exhibit. Although emotions might still not determine which learning goals will be met, they will likely set the right circumstances to make meaningful impact in some way, whether it is on a valuable personal experience, a lasting behavioral change, or the recalling of a memory. Therefore, emphasis will be put on aiming for an emotional experience at the exhibit.

Positive communication - The question remains what kind of communication strategy at the museum supports sustainable education. It is found that disastrous messaging of the scale of climate problems can provoke unintended attitudes, such as avoidance, rejection or denial [29, 30, 31]. Therefore, several studies argue that a focus on positive communication could be more effective [32, 34, 35]. For example, by showing people possible environmental solutions. This approach

encourages pro-environmental engagement, as it can fuel optimism [35], and constructive hope [32]. Moreover, it can be valuable to explain the sustainable benefits of innovative products in comparison to traditional products. This is shown in one study, where the perceived innovative value of a product was a strong predictor for the consumer acceptance towards insects in a human diet [114].

In summary, the results show there is an opportunity for museums to increase the general publics awareness of sustainability challenges through education. Communicating a positive outlook can help to increase peoples' belief that the sustainable challenges can be solved [55]. These recommendations are in line with the intended approach of the museum to educate visitors on future-oriented innovations, rather than problem-oriented challenges, such as the scale of environmental problems. Furthermore, the results from the literature research provided insights for the direction of the installation. For example, the exhibit will offer visitors a direct interactive experience with the sustainable objects, in order to increase visitors' emotional engagement. Second, the installation content should provide knowledge and facts about the innovative value of the novel materials. This will be done by showcasing the relevance of the products in the process towards a sustainable future.

Interactive learning in the museum

This chapter focused on understanding the role of museums in educating the general public. The concept of free-choice learning, and the consequential need for intrinsically motivated visitors in museum learning is discussed. Moreover, the principles to enable effective learning experiences is discussed.

Initially, the needs and wants that visitors have during their museum visit were reviewed. Visitors now expect to explore thoughtful exhibits that make an impact on how they feel, act and think [2]. It is found that museums are expected to take on a more active role in challenging visitors' viewpoints. This brings the opportunity for museums to become more involved in raising awareness on sustainable challenges. Moreover, it is found that exhibits combining hands-on and minds-on elements provide the most effective learning opportunities. Given the expectation of modern-day exhibits, they should allow interactions in the form of object-handling [39]. In the past, information was passively consumed from a distance. Museum visitors today increasingly want to get closer to the artifacts, and become part of an interactive experience. Given these insights, the installation should allow visitors to become an active part of the exhibit by offering hands-on interactions.

Museum learning framework - Due to the nature of museums as free-choice learning spaces, it is highly crucial to understand what drives visitor actions

throughout their museum visit. An established framework by Csikszentmihalyi was reviewed, which explains that intrinsic motivation is critical in driving the decisions of visitors in their learning process [36]. This framework is taken as inspiration for further research, as it provides useful insights in understanding how to grow visitors' intrinsic motivation to learn at a museum exhibit. The framework explains that exhibits should aim for an ultimate learning state, the 'flow' state, in which the visitor becomes completely immersed in the exhibit experience. In this state, visitors are highly intrinsically motivated to stay at the exhibit and learn about its content. The framework points out that intellectual, emotional and sensory attributes of exhibits are essential factors to enable such learning experiences. Thus, the installation will be designed with a specific focus on these attributes.

Intellectual attribute - To expand on Csikszentmihalyi's principles for museum exhibits, insights from several relevant studies are utilized for each of the three attributes. For the intellectual attribute, Cohen-Jones et al. [58], and Falk and Dierking [49], argue that intellectual stimulation in the museum is broader than the retention of hard facts. This includes physical discoveries, such as how an object feels, or how to handle an object, as well as mental discoveries that shape visitors' attitudes, beliefs or values. This philosophy for mental stimulation will be used for the design of the exhibit. Therefore, the exhibit will enable visitors to learn through their senses, through their own internal processes. Instead of focusing on providing only factual information, the exhibit will enable them to discover how the fabrics feel on their skin, and experience how they are produced.

Emotional attribute - Next, the emotional attribute of exhibits is reviewed. Peng explains that the 'emotional turn' is one of the most influential trends in increasing museum impact [39]. Two other studies add that museums should aim to evoke complex emotions, such as curiosity, besides basic emotions [64, 40]. Curiosity can be evoked by integrating unexplained stimuli, such as surprising sounds or objects, and curiosity can be sustained by offering information incrementally [36]. These insights can be used in the design of the installation, to keep visitors emotionally rewarded during their discovery process. For example, the installation can leverage the curiosity of visitors to find out that certain sustainable materials have stronger fibers, last longer or are biodegradable. On the other side, the installation could include certain physical interactions, making visitors curious about the way the installation reacts to their behavior.

Sensory attributes - Finally, the sensory attribute helps to encapsulate visitors in the exhibit with all their senses. At least two senses will be utilized in the exhibit to increase its immersive qualities [72]. Visual elements will be the main sensory input, but Greppi emphasizes the importance of audio for a direct induction of

emotions [63]. Moreover, object handling, and bodily interactions are important tactile sensations that will be integrated to maximize the impact of the sensory attribute [39]. To maximize impact of sensory elements, it is advised to use one key element, against contrasting lower-energy complementary elements [63]. For example, it would be effective to combine one bright light or spot with a dark surrounding, for a more dramatic effect. Another application could be by making important sounds stand out against background audio with a lower volume. These insights can be advantageous for the development of the installation.

Engaging challenge - Ultimately, the combination of the emotional, sensory and intellectual attributes results in an effective immersive learning experience. Csikszentmihalyi's framework concludes with the notion that immersion can be sustained if the visitor is challenged sufficiently during their 'task' in the exhibit. To increase immersion, visitors will get a challenge that they can complete throughout the exhibit experience. The importance of giving the visitor manageable goals, and providing immediate feedback will also be addressed [36]. Moreover, the study mentions that usability issues should be minimized, which can be done by providing clear expectations of the actions that visitors can do at the exhibit. This similar to providing affordances, which gives visitors a clear perception on how objects at the exhibit can be handled [56].

Exploring on-body projections

In this chapter, the current state of technology in museums was reviewed. Moreover, the direction for on-body projections in a museum exhibit is explored, as well as the technical considerations for a successful adoption of the technology. The findings are discussed here.

To understand how technology can be effectively implemented in a museum installation, the current state of new technologies in museums is reviewed. A major concern from the science community about technology in the museum is that it might draw attention away from real artifacts and museum environment [69, , 78, 79, 80, 81, 82]. This can obstruct visitors learning opportunities in the museum. To avoid distractions, technologies have been explored that are more naturally merged with the museum environment [100, 83, 89]. Projection-based technology is a promising technology for museums, as they can be seamlessly blended with the museum artifacts [88, 84, 90, 91]. The main advantage of projection-based installations is that virtual content and the museum environment are blended into one [4], removing the necessity of intermediate displays, such as head-wear or a screen. Furthermore, there are interesting indications that projections can provide a deep sense of unity between virtual content and the enriched objects. [7, 95].

Emotional effects - This form of emotional connection make on-body projections a promising direction for this project for three reasons. First, it aligns with the purpose of the exhibit, to introduce visitors to clothing items. Projections could augment this experience. Seconds, as previously established, emotions are a crucial part of the impact of an exhibit experience. Third, impacting visitors emotionally is even more important when involving visitors with sustainable development. As stated by studies in section 3.1, the emotional impact of exhibits is a consistent predictor for visitors' involvement with sustainable behavior [16, 22]. Thus, striving for emotional connection with the exhibit content is highly promising for the purpose of this study. However, it remains unknown how an emotional connection between on-body projections and objects might emerge. Moreover, a deeper understanding of the emotional effects is yet to be gained. Exploring the emotional perception of on-body projections is deemed as a highly suitable opportunity for this study. Therefore, it is chosen to further investigate the use of on-body projections in research with the museum exhibit.

Implementing on-body projections - After validating on-body projections as a novel research opportunity, projection-based technologies were reviewed for further insights on successful implementation. Due to the scarce research of projection-based technology in museums, both projections onto flat surfaces, as well as physical objects have been reviewed. Here it was quickly found that some projection-based techniques, such as 3D projection mapping, make use of motion prediction algorithms. However, such techniques are considered too advanced for the scope and resources of this project. Fortunately, there are more feasible ways to implement on-body projections. For example, projections can be placed onto still objects, to avoid the need for real-time projection-mapping. For obvious reasons, this might compromise the flexibility or robustness of the system. However, experiments with such design setups will be done to keep the development of projection-based technology feasible, while still holding the benefits of enriching physical objects with a virtual layer.

Evaluating learning at the exhibit

Next, understanding how to evaluate the effectiveness of museum exhibits is crucial for progression in design research. In this chapter, the evaluation methods that are useful for the objectives of this project are described. This includes how to assess the learning opportunities of the exhibit, as well as how to explore its emotional aspects in more detail.

Emotions for sustainable development - As explained in chapter 3.1, the key predictor for effective environmental education is the induction of emotions [18,

24, 16, 27, 22]. As it is such a crucial aspect for making an impact on sustainable education, it is decided to not only use this as a driving principle for the research in this project and the design direction, but to also as a key indicator of the effectiveness of the exhibit. However, according to Peng, traditional evaluative research on interactive exhibits generally fall short in measuring the emotional aspects of a visitor experience. Therefore, an emotional scale was sought that could be included in the evaluation of the exhibit. The Other in Self scale by Aron et. al. seemed suitable, as it measures the emotional connection people perceive with another entity [98]. Therefore, it could reveal visitors' perceived emotional connection with the exhibit content. The scale could then be used as a basis for further investigation of the emotional effects through a qualitative in-depth interview. Campos et. al.'s advice for including open-ended questions will be followed, to identify possible underlying factors [56].

Assessing learning opportunities -

According to Hein, it is evident that visitors learn in the museum through a process of free-learning [26]. However, measuring learning outcomes of exhibits can prove to be problematic. It is challenging to capture the vast ways that visitors learn in the museum in a research experiment. This is similar for assessing learning about sustainable development in the museum. Due to the various backgrounds, motivations, and attitudes of visitors, it can be notoriously hard to determine the impact that exhibits had on their meaning-making of environmental issues. Falk and Dierking argue that this is because every visitor enters with different backgrounds, motivations, and values [22]. Also, Falk and Dierking state that it is unrealistic that a significant change in peoples' world views take place in one museum visit [22]. Even if changes are observed right after the experience, they might not persist over time [16]. Therefore, researchers might need to think more broadly about the learning impact of exhibits. Therefore, a more broad perspective will be taken on the meaning of effective learning opportunities in the museum. Potential measurement scales will be reviewed with this viewpoint in mind, to capture the wide range of learning possibilities.

For example, instead of evaluating concrete learning outcomes, it can be crucial to understand whether the exhibit has enabled an effective learning opportunity. As described, the framework by Csikszentmihalyi provides the basic ingredients that are essential for more effective learning opportunities [36]. As internal motivation is highly important in museum learning, the framework includes principles for sensory, intellectual, and emotional stimulation, and an engaging challenge. When these principles are effectively integrated, it is more likely that a meaningful learning opportunity has been established. However, there is no evaluation scale included in the framework to validate whether a learning opportunity is enabled. A closely related scale was found in the Museum Experience Scale, developed

by Othman et. al. [9]. The variables in the scale seemed to closest resemble the principles of the framework. For example, intrinsic motivators such as the emotional and intellectual attributes, and exhibit challenge could be linked to the Emotional Connection, Knowledge/Learning, and Engagement variables of the MES scale. The remaining sensory attribute and Meaningful Experience had a weaker link. Despite this, it was deemed to be the most relevant scale to measure visitors' learning opportunity as proposed by the museum learning framework. Another benefit is that this experience scale is specifically tailored to museum spaces, and it includes the evaluation of emotional arousal, which is a consistent predictor for effective sustainable education [16, 22], but it is not often included in exhibit impact evaluations [39].

4 Similar work

There is an opportunity for museums to explore the potential of on-body projection-based exhibits, for a more seamless and natural integration of technology with the museum environment, as discussed in section 3.3. In this chapter, several cases from research that incorporate on-body projection-based systems will be elaborated. As there are relatively few exhibits including on-body projections, projection-based installations onto surfaces are reviewed as well. The chapter includes promising non-scientific on-body projection-based systems for further inspiration. The reviewed previous works served as a guideline for the further development of an on-body projection installation.

4.1 Projection-based installations on screens

In this section, projection-based installations in museum exhibits are discussed, that are projected onto screens. The descriptions include the factors that played a role in the effectiveness of the installations. Their relevant conceptual ideas, engaging elements, and technical parameters could then be used as inspiration for this project.

Kirini

Kirini is an installation that follows an interactive narrative about beekeeping heritage in the island region of Cyclades in Greece (see figure 12) [100]. It consists of an interactive documentary that is projected onto multiple consecutive walls, and the visitor has to execute certain tasks in the scenario to learn more about beekeeping. They can do so by physically interacting with the objects in different ways. To find out more about the islands' history of beekeeping, visitors can open more information by touching islands on the projection wall. The sensors used for the selection of the islands were cloth covered by electric paints that were controlled by Bare Conductive Touch Boards. In another task, visitors were asked to push a tangible card that represents a honeycomb frame in the right slot. In all tasks, the user stood in front of the projections. When standing close to the wall, the user was partly covered by the projection, but there are no suggestions that this was an intended part of the interaction. It is not measured whether this affected the experience in any way, or if it made the user feel more part of the scene. They found that rich animated objects and visuals helped to better engage users

in all experimental conditions. Moreover, an important finding was that friction due to usability issues obstructed engagement. Therefore, they advise to make explanations for interaction as clear as possible. The researchers also explain that audio feedback gave visitors a better understanding of their performance, which helped to reduce this friction.

Figure 12: Kirini installation [100]

Boundary Functions

Snibbe and Raffle evaluated several of interactive installations for museums [76]. Boundary Functions is one of the interactive installations in which visitors explore a mathematical pattern on a 4x4 meter floor (see figure 13). Lines are projected as boundaries between visitors. The position of the visitor is captured by a camera sensor, and the tiles shift accordingly. In this installation, multiple users stand on top of the projections. As the lines are intentionally placed between the users, they are not covered by the projections. Although the animations of the installation are minimalistic, the visceral feature of the animations made the installation highly engaging. Moreover, the researchers explain the effectiveness of the installation through its social interactions: it encourages visitors to interact with each other, as the pattern changes and becomes more complex when more visitors join the floor. The experiential narrative of the installation is found to be effective in extending the duration of visitor interactions, as visitors tend to explore how the installation responds to their movements for longer periods of time.

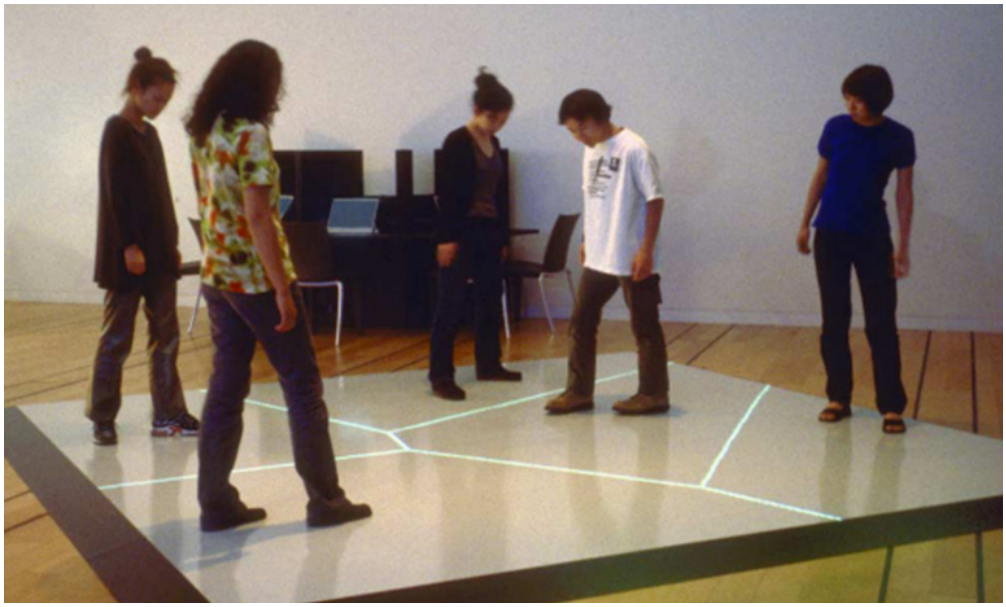


Figure 13: Boundary Functions [76]

Three Drops

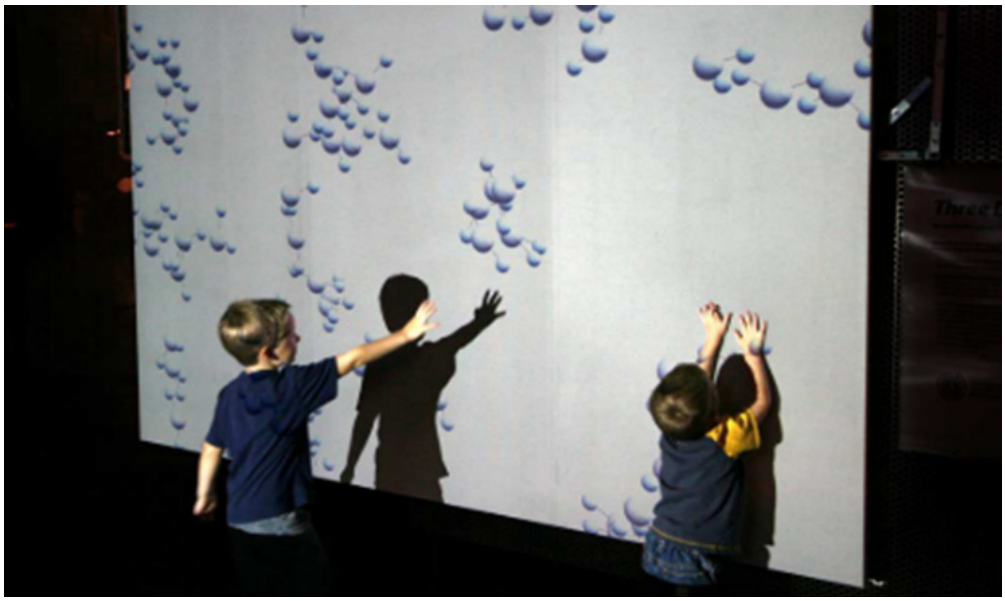


Figure 14: Three Drops by Snibbe and Raffle [76]

Three Drops is another installation by Snibbe and Raffle that enhances visitor engagement through projection-based technology (see figure 14) [76]. It is an interactive wall that immerses the visitors of a science museum with a projection on a wall. On the wall, visitors can experience the properties of water at different scales. With their shadow as an interactive body, visitors can take a shower, stick the surface of water droplets to their body, and interact with a chain of water molecules. In each interaction, the water responds to the bodily movements of the visitor. In the installation, the user stands in front of the projected wall, facing the visuals. Their bodies are covered by the projections when interacting with the wall,

due to the positioning of the projector. However, this is not a main experiential feature for the visitors themselves, as they face the background instead. The installation is considered engaging through its complex animations that reveal how water behaves at different scale levels. The researcher argues that the whole-body interactions enhanced the visitor engagement. Moreover, ambient sounds are implemented to give the user a better impression of their environment.

Fear

The last installation by Snibbe and Raffle is the interactive projection-based game 'Fear' (see figure 15) [76]. The media is projected onto a wall, and visitor silhouettes are projected on top of the scene. In the installation, visitors can catch fruits from a tree by holding their arms in the air, while they have to avoid their movements being detected by a tiger that moves from left to right. The objective of the game has a binary outcome rather than continuous variations (detected by the tiger, versus not detected by the tiger). The users interact with the system from a distance. Therefore, they are not covered by the projection lights. According to the researcher, this narrative encourages a shorter interactive experience than the other installations, like 'Three Drops' and 'Boundary Functions'. Nonetheless, the installation is popular due to its game-like features. Moreover, it triggers cooperative and competitive behavior in visitors interacting together. The researcher found that the visitors started helping each other collecting fruits by passing fruit to the next person, while some visitors entertained themselves by pushing others playfully to cause an attack by the tiger.

Figure 15: Fear by Snibbe and Raffle [76]

4.2 Projection-based installations on bodies

Besides projection-based installations that use flat surfaces to project on, there are several state-of-the-art works that are aimed at projections onto physical objects. As this is a relatively novel approach, case studies from both academic research on museum learning, as well as other research areas are reviewed. In this section, the parameters that are chosen for the technological applications are discussed, as well as the feasibility, relevance and limitations of the works.

Glowing Pathfinder Bugs

Figure 16: The Glowing Pathfinder Bugs installation [84]

Glowing Pathfinder Bugs is a sandbox installation aimed at engaging visitors of public exhibitions (see figure 16). Crawling insects are projected onto the sand by a projector hanging above it [84], and visitors are able to interact with the virtual insects by getting their hands close and lifting them off the ground. To detect the location of the visitors' hands, the system makes use of a depth camera with stereo vision. This also helped to ensure the right size of the insects for different elevations. It is unclear whether this study incorporated projection-mapping techniques in their system.

In this installation, the virtual bugs are projected onto different surfaces, such as a sandbox, a flat table, the floor, and bean bags. This was done to create the perception that the digital content is embodied in the space, rather than existing in a bordered frame. Moreover, the virtual bugs are intentionally projected onto the users' hands. This way, the researchers hoped to unify the users with the animated creatures, thereby enhancing emotional engagement. To enhance engagement, the authors incorporated surprising elements for the bug interactions. When two creatures met, they would combine into one, eventually flying off as a butterfly. On the other hand, when an insect was handled too roughly, it would either panic or pop into disappearance. The researchers found that because of this feature, multiple of the visitors started hammering the insects, challenging themselves

to kill them all. The researchers observed that other visitors would in turn try to protect the insects from the killing spree. Although it was not an intended outcome, the researchers found that these somewhat cruel interactions were considered to be highly engaging.

Inside Out

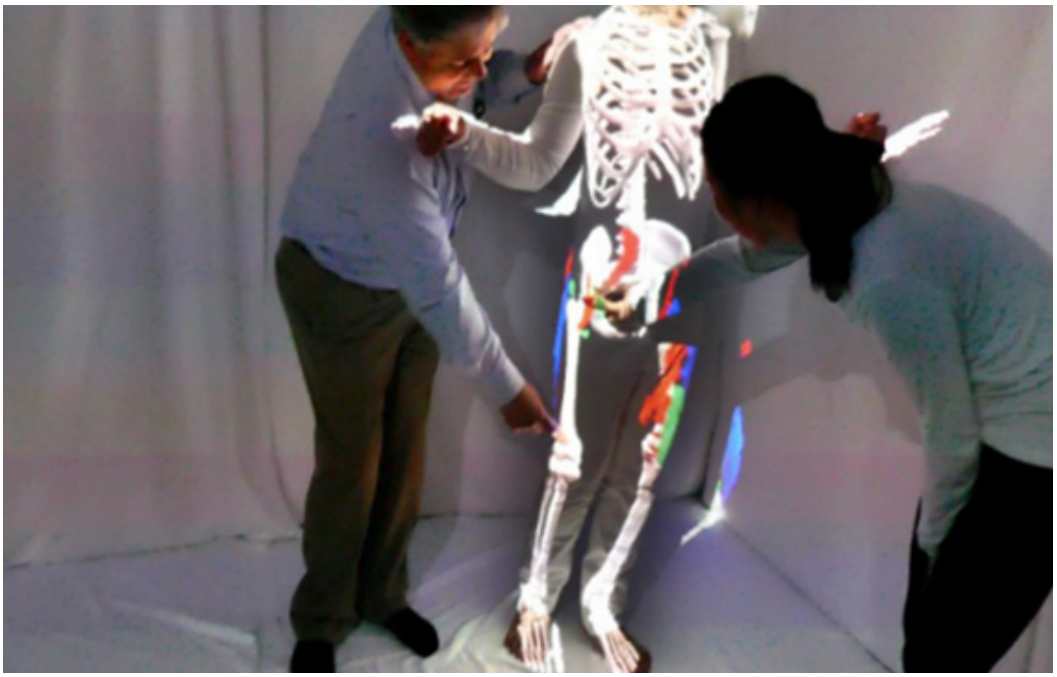


Figure 17: Physiotherapist students interacting with Inside Out [101]

Hoang et al. explore the concept of an on-body projection system as an educational tool (see figure 17) [101]. The researchers build a system that projects different body systems onto the wearer, like a blood circulation, a skeleton and a muscular view. In this project, the use of the system is tested for teaching physiotherapy students. The projection-based system collects the posture estimation that is included in the depth sensor, which allows for dynamic movements in front of the camera. This way, researchers were able to investigate the body as a canvas, and also how the system should respond to the wearer's movements. The projected content was overlayed on the body using a technique called skinning, which is a way of binding a mesh layer to a dynamic skeleton. The system makes use of two front-facing projectors at a 90 degree, to include the sides of the body in the projection. The researchers found that the system enhances the student learning experience, and gives them a better understanding of human anatomy. The students found it very useful to observe the anatomical structures through dynamic movements. In a follow-up study with the same installation, the researchers found that people felt a strong connection with the displayed content

[8]. Moreover, the system supported enhanced interactions between the teacher, the observing students and the volunteering student.

Interactive arts at Burning Man

Baroya presents an interactive installation for dynamic on-body projections in an art show [95] (see figure 18). In this work, a novel technique is used to minimize errors and predict user poses. The main goal was to reduce the time from calculating the placement for the mesh to the display on the body. This is done through the design of an interactive arts system, that displays butterflies and eye pupils on top of the target's body. With movements, the user can interact with the visuals. The system makes use of three Azure Kinect devices in a chain, which are depth sensors that allow for body tracking. By using multiple devices, the image range is higher, occlusions are captured, and surface objects are captured in three dimensions. This results in more robust readings of the data. The Kinect SDK then produces the body points that are captured from the images. The main part of this study is the addition to the body joints of a motion prediction algorithm, as well as an algorithm that minimizes tracking errors. Although the results are deemed successful by the author, the system is not yet evaluated with real users.

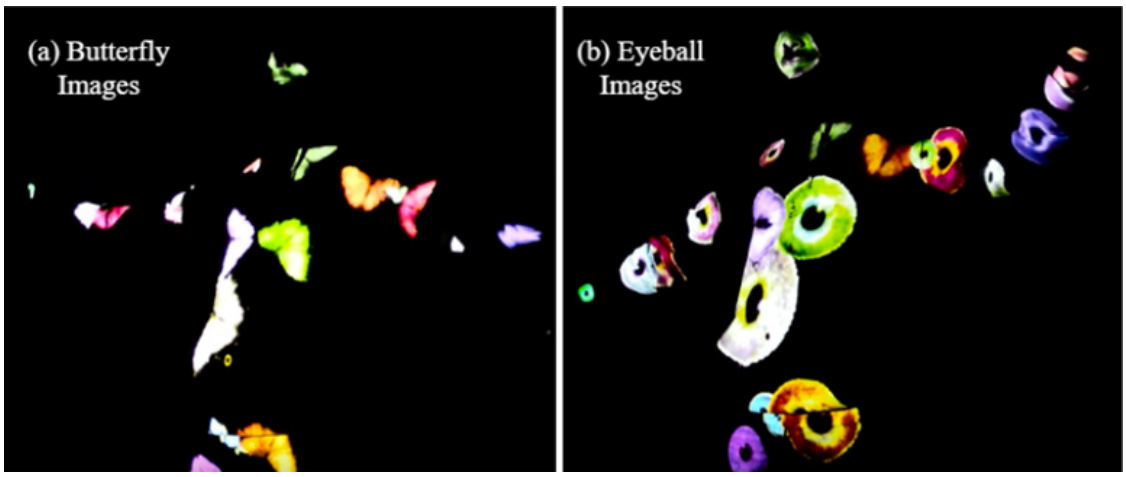


Figure 18: Dynamic on-body projections in the interactive arts [95]

4.3 Non-academic on-body projections

Besides academic projects, there are multiple installations in artistic or commercial fields that incorporate on-body projections into their interactive installations. Although their impact is not scientifically validated, the recent increase in development indicates that on-body projections hold potential in enhancing user experiences. Therefore, the features of three artistic installations are discussed in this paragraph.

Transcending Boundaries

Transcending Boundaries is an artistic piece that is made by teamLab in Tokyo (see figure 19) [102]. In the piece, morphing flowers are projected onto the spectators in a dark room. The aim is to grow appreciation for nature through a sense of wonder. The artist aims to do this by building a stronger connection between humans and nature, by creating a borderless unity between the visitors and the immersive art. An interaction is established by letting the flowers respond to the visitors' movements. When the visitor stands still, the flowers grow in numbers. Rapid movements of the visitor cause the flowers to fade. The main surface of the projection are the users, as they are completely covered by the virtual projections. Through movements they can discover how the flowers respond to their body. It is unknown how the on-body projections in this project affect the user experience, but it clearly intends to make the experience more immersive. Moreover, the artists' intention is to enhance the sense of unity between the visitor and the virtual flowers, but this effect is not yet explored scientifically.

Figure 19: Transcending Boundaries (https://www.teamlab.art/e/trancendingboundaries/) [102]

Light Painting

'Light Painting' by Red Paper Heart is another on-body projection-based project that aims to encapsulate users in the drawings made by their friends (see figure 20) [103]. One user stands in front of a projected wall, while another makes drawings on a phone in front of the installation. The drawings are sent in real-time to the projector, and are projected onto the wall and the user in front of it. This way, the wall, the users, and the art merge into 'one', each becoming a part of the visual spectacle. The installation included reactive visuals that responded

to the music in the environment, as the destination for the installation was at a music event. According to the authors, people that entered the installation site made drawings on top of their friends, while dancing and taking pictures. With this notion the artists indicate that users are engaged with the system, but this has not been evaluated in a study. Moreover, it is unclear to what extent the user experience was affected by the on-body features for both the bystanders, as well as the users in front of the wall.

Figure 20: Light Painting (Red Paper Heart) [103]

4.4 Similar work: conclusion

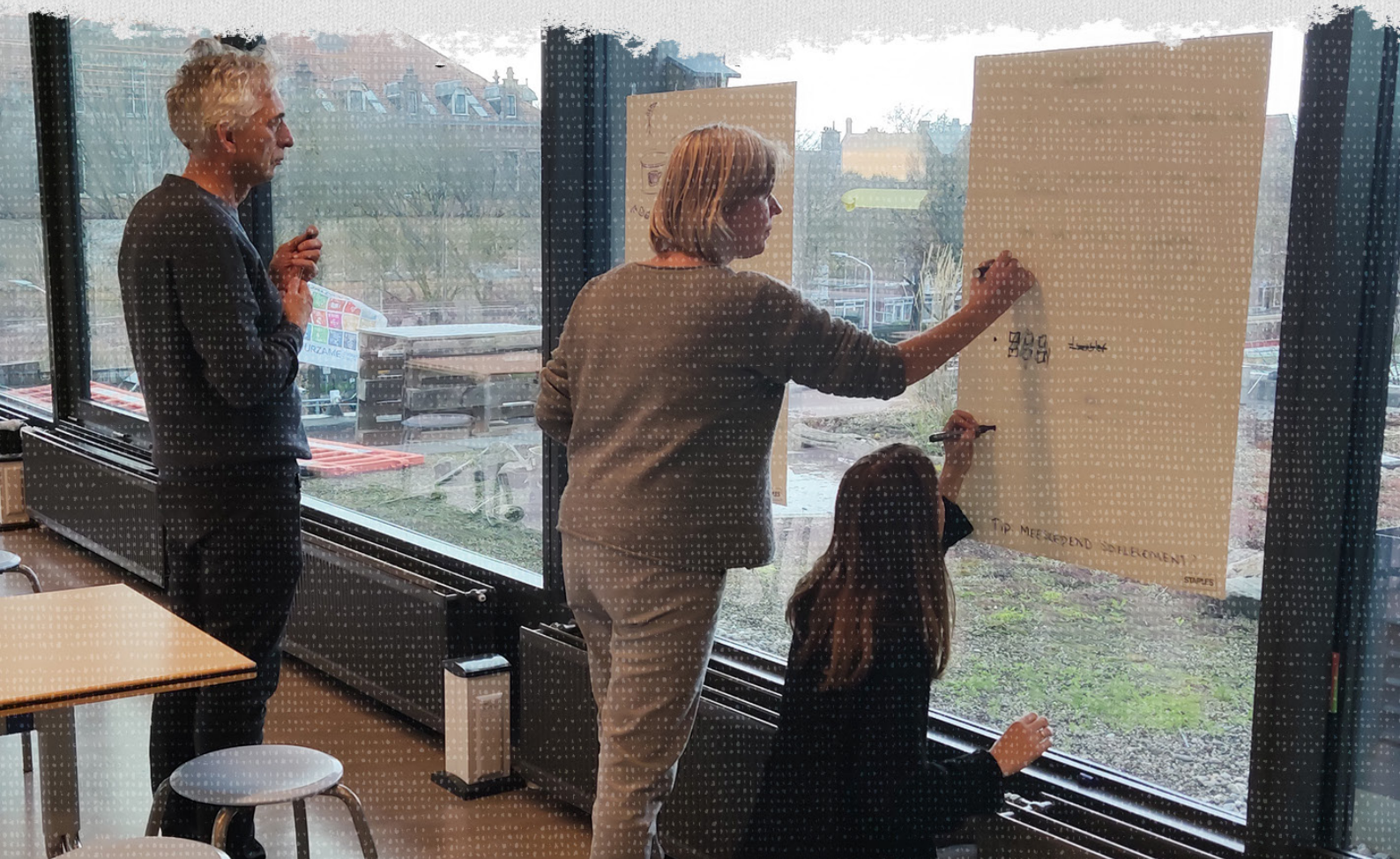
In the previous works, multiple use cases on projection installations are reviewed. Kirini, Boundary functions, Three Drops, Glowing Pathfinder Bugs, and Fear are examples of museum installations that incorporate projection-based technologies [76, 84, 101, 100, 102]. However, none of the installations utilize the bodies of visitors as an information display. Several non-scientific installations integrated on-body projections for more immersive user experiences. Only two scientific studies were found in which on-body projections were incorporated. Their results indicate that there is high potential for on-body projections for increasing the emotional impact of virtual content. For example, the Glowing Pathfinder Bugs project shows that on-body content can produce an engaging and fascinating experience for users [84]. The researchers from the Inside Out installation explained that participants felt a stronger connection between themselves and the content projected onto their bodies [8]. Interestingly, this perceived effect was also reported by participants that merely observed the on-body projections onto

someone else. However, these studies only evaluated the installation as a whole, while the effect of the on-body feature was not measured separately.

After reviewing similar work, ideas are collected on how to integrate on-body projections in a museum exhibit. This includes the use of rich visual content, and atmospheric sounds. For the concept, an experiential or game-like narrative seems fitting for this assignment. Furthermore, the review of the installations produced insights on how to let visitors interact with an on-body system. Whole-body interactions were most often used in interactions. To capture the visitors' movements, depth sensors and body tracking software was used. Furthermore, the installations provided insights in the technical parameters that can be chosen. For example, the amount of projectors used ranged from one up to three projectors. With more projectors, more angles of an object can be projected. Furthermore, most projectors seemed to be mounted onto the ceiling, as this reduces the risk of visitors touching or breaking the system.

Section 3

Development



5 Ideation

Based on the related work in the previous chapter, a research gap to investigate on-body projections was identified, and guidelines for designing an on-body projection museum exhibit were collected. At this point, a challenge that people can do at the exhibit remained undecided. Moreover, a more concrete understanding of the requirements for the system was still necessary. Therefore, the ideation stage was used to decide more concretely on the content of the on-body installation, and to gather critical requirements from employees.

5.1 Requirements

To foster meaningful learning opportunities at museum exhibits, it is important to provide visitors an engaging challenge [36]. As a suitable challenge still had to be generated for the on-body projection exhibit, an ideation session was conducted with employees. This way, possible challenges for the installation were collected, while utilizing the experience of the employees. At the same time, the session helped to provide a better understanding of the requirements of a museum exhibit. The brainstorm session was followed by a group discussion. This provided insights into the employees' point of view and their considerations for each idea. Overall, the session helped to understand what constitutes an engaging and suitable challenge for the exhibit.

The method 'brainwriting' was used, which is an effective brainstorm method where ideas are written down individually, after which they are discussed in the group [104]. This is an academically validated technique for more fruitful and qualitative idea generation sessions. As most of the employees were not familiar with the possibilities and limitations of on-body projection systems, doing a brainstorm within the scope of on-body projections could be ineffective. Moreover, for brainstorms in general, it is generally embraced to encourage free thinking. Therefore, it was decided to brainstorm on engaging challenges for exhibits in general. The challenges with the potential could then be converted to on-body design of the system.

Setup

In total, five employees took part in the brainwriting session (see figure 23). The employees had a diverse range of characteristics in terms of gender, age, involvement in the project and expertise, to ensure a broad range of perspectives.

A total of 5 employees participated, of which 3 were male and 2 were female, and their age ranged between 30 and 60 years old. 3 of the employees had worked to some extent on the development of the 'One Planet NOW!' exhibition, whereas 2 of the employees entered the session without any prejudices. Finally, 4 of the employees worked at the museum over five years, and 1 employee started working this year.

The 30-minute brainwriting session was organized in a large, and quiet office space. The main design question was formulated: "What kind of exhibit challenge can make the discovery of sustainable fabrics more engaging?". This was written down on an A3 paper in the front of the room. Five A3 papers were placed on walls throughout the space. Each paper contained a suggestion from the literature, that employees could consult if they were out of ideas (e.g. enhancing curiosity, enabling social interactions between visitors, stimulating the senses, engaging challenge, and intellectual stimulation). This way, findings from the literature were integrated into the brainstorm as possible solution directions, while still encouraging the employees to think freely.

Every employee was asked to write down an idea on the paper in front of them in two minutes. They were encouraged to make a sketch of their ideas in order to make them more imaginative and vivid. As a playful encouragement for sketching, they received a peppernut (a Dutch snack for the seasonal event 'Sinterklaas') as a treat for every sketch. After two minutes each person was asked to turn clockwise to the next paper. The employees wrote their ideas below the ideas that were written down by the previous person. This way, associative thinking was stimulated, as the employees took inspiration from what the previous person wrote down (see Appendix A for references of the filled-in papers).

After all ideas were collected, the employees were asked to vote on the top five ideas they found most promising. This resulted in an overview of the most promising ideas from the brainstorm session. The ideas that had at least one vote were discussed in the group. This resulted in an understanding of the advantages and disadvantages of each idea. Through the discussion of the ideas, the requirements for the system were revealed. For example, discussing an idea for tasting coffee beans led to an understanding that permanent exhibits should preferably not require the use of refillable items or loose objects. Therefore, discussing several ideas proved to be an excellent strategy to uncover hidden requirements for the system.

Generated challenges

The goal of this part of the session was to gather ideas for the challenge within the exhibit. A list of challenges was produced that were considered most engaging (see Appendix A). The top-voted ideas were then discussed with the employees,

so they could express the advantages and disadvantages of their suggested ideas. The three top-voted ideas for a challenge (Table 1) and the discussed advantages and disadvantages are described below.

Self-reflection – This challenge focused on encouraging visitors to express their own personal viewpoints. At the stage visitors can give their opinion about the sustainable fabrics, and give an answer to questions like: "How happy do you think the planet is with this piece of clothing?". They can answer the question by picking a smiley ranging from sad to happy, for example. Two employees discussed that it is generally engaging for visitors to make a comparison between their opinion and the ones of previous visitors. Although this idea was amongst the highest voted, it became clear that there were already several similar opinion-oriented exhibits in the exhibition. Therefore, the employees concluded that the idea does not have enough original value.

A game quiz – The second idea was to make a quiz on the stage. It was suggested to split the background in two with one material on each side. Visitors would then need to guess the material of the shirt that they are wearing, by moving to the right side of the stage. The system would tell whether their answer was correct and give them a score, in terms of how fast they answered or how many correct answers they have given. However, one employee noted that there are two more similar quizzes in the exhibition. Therefore, this challenge would have little original value. More importantly, in a later assessment, it remained unclear how to translate the quiz into suitable content for the on-body projections.

Pick the right item – The third idea is similar to the challenge in the previous quiz, but in a reversed form. In this idea, the material is showcased onto the stage, and the visitor is challenged to pick the right piece of clothing from the rack. The ideas with quiz-like challenges were high in ranking, but several installations at the exhibition already utilize a challenge in the form of a quiz. To include a diverse range of exhibit experiences, the majority of employees agreed that the concept should be more original. Additionally, the core interaction would be that the visitor picks the right piece of clothing. This leaves little room to establish an immersive experience. Therefore, this idea neither seemed suitable for a conversion to the on-body projections installation. Therefore, the idea was discarded after the brainstorm session.

Table 1: Top three ideas

1.	Self-reflection: How happy do you think the planet is with this piece of clothing?	3 votes

2.	Game quiz: Splitting the background with two different materials on each side. Guessing which is the right one that the visitor is wearing	3 votes
3.	Pick the right item: Choose an item at the clothing racks which you think the fabric is made of. Stand on the stage with the item and the system will give you points if you were right	2 votes

Requirements for the exhibit

Although this list of generated ideas did not result in a suitable concept, the next part of the session, the discussion, produced useful insights for uncovered requirements of the installation. A better understanding of the thoughts and wishes of the employees was gained, and the discussed points could be used as requirements for the system. The requirements were also discussed with the museum's supervisor, to ensure a correct understanding of the wants and needs for the installation. The requirements are listed below.

The fashion store - A clear understanding was gained on which parts of the exhibit were predetermined, and where there still was free creative space. For example, it became clear that the setup for the fashion store was predetermined. There would be a clothing rack, where visitors can pick a clothing piece made from a sustainable material. Fitting rooms would be placed in which the visitor can try out the clothing items. At the stage, the visitor would then be enabled to learn about the material through an immersive experience. Deciding what the experience at the stage would look like, was the main objective of this project.

Immersive soundscape - The majority of the employees agreed that sounds are an essential part of an exhibit experience. Ideas were discussed about sounds that could make the experience more immersive. For example, sounds could be added that give visitors an impression of the environment in which the product of the fabric originates. For example, for bamboo, rattling chimes could be played as a sound effect. Simultaneously, Asian background music could be added to the exhibit. This would result in an immersive soundscape that enhances the visitors' sensory experience. The multi sensory discovery makes learning about the sustainable fabrics more engaging.

Educational message - The installation should have educative value, besides merely providing a fun challenge. However, younger children are a major proportion of the visitors at the museum. Therefore, the installation should be suitable and accessible for children aged 6 and older. It would be undesirable to present advanced quantitative comparisons of the fabrics, for example. Rather the educational information should be presented in shorter, and more digestible

messages. Nonetheless, the employees desired an educational takeaway at the exhibit.

Robustness - The employees told from experience that exhibit elements tend to get stolen or damaged quickly. Therefore, the robustness of the system is essential. This was found during the discussion of one challenge, in which it was suggested to let visitors smell and feel the actual materials, such as coffee beans. However, such loose objects have to be monitored, maintained, and were therefore not feasible for permanent installations. Instead, the installation should have its major parts attached to a solid construction. To ensure a sufficient robustness of the system beyond this thesis project, the construction of the installation would be built with the help of experienced employees.

5.2 Concept ideation

In the previous phase, important requirements were collected, but a suitable challenge remained uncovered. Therefore, a personal brainstorm took place to ideate on more suitable challenges. The ideated concepts were tested for their suitability and a final concept was chosen. Due to time constraints, the concepts could not be tested with visitors. Instead, the concepts were discussed in multiple meetings with employees, which helped to shape to the final concept for the installation. The different concepts, and the considerations for each conceptual direction are discussed in this chapter.

Restrictive conditions for the concept

During this part of the project, some restrictive conditions were brought up that can inevitably be part of a real-life study case. One of them is that the lightning conditions of the area cannot be altered, despite the theoretical advice to set up a dark environment [89]. It is estimated that this can decrease the visual impact of the installation, and consequently the visitor experience. Unfortunately, this was an unavoidable condition that might influence the effect of the on-body projections. This should be kept in mind when interpreting the study results. Moreover, ideally the clothing items would consist of pale and bright colors. However, at this stage it was discovered that the fashion partners from the museum only had saturated and colored clothing available. Although this could impact the colors of the projections, there were no alternatives available. The combination of the lightning in the room and the colors of the clothing items, would most likely affect the impact of the projections. Therefore, the content for the projections would need to be picked for its suitability on the worn clothing. In the next section, experiments were conducted in which the lightning of the museum environment and the saturated clothes were

recreated. This way, different kinds of content could be tested thoroughly.

Reflect to Grow

The first idea was to project an image or animated movie of each material onto the clothing of the visitors. When tests were done with a projector and an image of a tree, it looked visually interesting. However, some form of interaction had to be integrated in this concept. One idea was to make the materials reactive, in a similar manner as the flowers in the Transcending Boundaries project (see section 4.3) For example, when the visitor stands quietly, the material (e.g. twigs for the eucalyptus tree, beans for the coffee grind, cap bottles for the PET bottles, et cetera) would gather in growing numbers onto the visitor, and fade away when the visitor starts moving. This is a symbolic reminder for taking a moment to reflect upon the sustainable challenges in the world. It shows visitors that literally slowing down, rather than rushing back into their regular lifestyle, can help to evolve a more prosperous future. Moreover, by slowing down and choosing responsible products, they can help to produce more sustainable resources. Another idea was to show the visitor how much of the material is needed for the production of the clothing. The materials would drop onto the visitor, and slowly 'fill' their body with the material. When the visitor jumps up and down, the material moves as if pulled by gravity for an experiential effect.

Evaluation Reflect to Grow - Both versions of the concept were considered to be original, and of high experiential value. However, as established in the previous section, the suitability of the content needed to be tested under varying circumstances. For this, a test was set up, in which the museum environment under varying light circumstances was recreated (see figure 21). The lights in the room were initially turned off and a white shirt was used. This was done to see the effect of the projections in an ideal environment. In the ideal environment, the visuals looked effectively realistic. Next, a red shirt was used for experimentation with saturated clothes. Additionally, the light in the room was turned on, to resemble the museum environment. In the final experiment, the projections were not as vivid and sharp. The recognizability of the PET bottles was deemed insufficient when it was projected in the third experiment. Therefore, it was decided to discard the concept, and first explore other types of content.

Figure 21: PET bottle objects in best, mediocre, and worst conditions

Body as a Looking Glass

This idea involved an immersive background on the wall containing video footage of the sustainable material (e.g. an eucalyptus forest for eucalyptus, sheep grazing in a field for wool, PET bottles drifting in the ocean). However, the background would initially be hidden. The visitor would be challenged to discover the sustainable materials by using their body as a 'looking glass'. When visitors move onto the stage, their body would function as a window to look through, revealing parts of the background (see figure 22). There were two versions of this idea. The first was that the 'masked window' moves along with the body of the visitor. This way, the background will only be visible on the visitors' body. The second version would involve a mechanic similar to a scratch card. In this version, the parts of the background that the visitor passes will be 'scratched' open. The parts of the video becomes visible when the visitor passes the location. The visitor can reveal the full background by moving around. The first idea is a more experiential interaction, whereas the second involves a challenge that can be completed.

Evaluation Body as a Looking Glass - The second concept was considered to be highly original, and of high experiential value. It consist of features that can enhance curiosity, while also providing a challenge that visitors can complete. However, besides experiential value, there is little educative value in this concept. Preferably, the system would enable visitors to learn more about the sustainable characteristics of the materials. However, the most critical setback of this concept involved the visibility of the content. Similar to the Reflect to Grow challenge, the visibility of the content was on the lower side in the experiment resembling the museum environment (see right image of figure 25). The background video

contained relatively many details, which was found to be unsuitable for the poor lightning conditions. Moreover, the recognizability of the images highly decreased when it was projected onto colorful clothing, and the details became ill defined on a moving body. This negatively affected the overall impact of the experience. Therefore, it was decided to ideate on content without too many details and with easier recognizability.

Figure 22: Video footage of PET bottles in best, mediocre, and worst conditions

Catch Sustainable Facts

In this concept, the visitor learns what sustainable materials the clothing items are made of through a playful discovery. The clothing items on the rack contain a label with a mysterious hint. However, the actual sustainable material that they are made of is not yet revealed. The visitor is invited to put on one of the clothing items and step onto the stage. On the stage, question marks start appearing onto the background. The visitor can 'catch' the question marks, and when they succeed, they receive more hints about the material. This way, the visitor is encouraged to guess what could be the answer. All of the hints revolve around the sustainable qualities of the materials, so that the visitor learns about their sustainable value while playing. The sustainable qualities of the materials are projected as texts onto the visitors' body. As the target age is 6 years old and above, the text messages should be on the short and simple side. At the end of the sequence, the sustainable material is revealed. The name of the material is also projected as text onto their body. This way, the experience contains a 'journey' that utilizes the curiosity of the visitor. Visitors can learn about the value of the sustainable clothing through a playful discovery. For sensory stimulation,

the background would be filled with rich scenery of the material. Initially, the background starts out blurry, in order to not immediately give away the sustainable material. At every caught question mark, the background becomes more sharp, while facts about the material are simultaneously explained. At the final swipe, the actual material is revealed as a textual print onto the shirt of the visitor.

Evaluation Catch Sustainable Facts - Compared to the other concepts, the content in this concept was found to be most suitable for the restrictive lightning conditions. During testing, the texts were clearly readable, even in the harshest environmental conditions (see figure 23). This was likely due to the relatively low amount of details in the text. Additionally, the white text was clearly recognizable in all experiments. Unfortunately, the text highly absorbed the red color of the shirt, which turned the white text into red text. Despite this, the texts remained clearly readable onto the projection surfaces. Therefore, this concept had the highest visual impact. Moreover, the sustainable messages seemed to be a suitable fit for the goal of the on-body projections. The visitors might be more likely to associate the messages with themselves, when they are projected onto them. Another favorable point of this concept was that it enables visitors to learn about the sustainable characteristics of the materials, thereby increasing the educational value of the concept. Finally, catching of the question marks can provide an engaging challenge that can be completed. For these reasons, this concept was chosen for further development.

Figure 23: Text for PET bottles in worst, mediocre and best conditions

6 Development

After the concept was chosen, it was time to start developing the installation. The development phase consisted of refining the concept, further developing the design elements, building the hardware and software, and letting all parts of the system come together into one immersive visitor experience. The process of developing the system is discussed in this chapter.

6.1 Design development

At this stage, the system was developed. The responsibilities in this work included the creative direction, software development, and user studies with the installation. The interior designer, project manager, and construction worker were partly responsible for the collection of clothes, writing the educative material, printing the information displays, and the construction of the exhibit, respectively. The resulting installation is discussed in the next paragraphs.

Sustainable properties of the fabrics

Although not the main focus of this project, the fabrics in the exhibit should have more environmental-friendly potential than their traditional counterparts. The employees formed a diverse selection of items from sustainable fabrics that were original and informative. The initial selection of fabrics was done by the museum employees, and added to the exhibit content after investigation by the author. The sustainable qualities of the fabrics were reviewed, which resulted in a selection of fabrics that is listed below. Their sustainable benefits of each material is described as well.

Plastic bottles - Plastic PET bottles are a major contributor to plastic waste. One study estimates that PET plastic accounts for 18% of worldwide production of plastics [105], and 1 million PET bottles are wasted every minute [106]. Up-cycling these materials leads to a reduced amount of waste, as well as a decreased production of plastic yarn [107]. However, with the up-cycling of plastics, the problem of micro-plastics persists. For this reason, the fabric is not ultimately sustainable. Nonetheless, it can be regarded as a temporary solution for the disposal of waste.

Coffee beans - Coffee is a popular beverage in countries all over the world. Each day, an estimated amount of 3.5 billion coffee cups are consumed [108]. During the production of coffee, it is estimated that only 5% of the coffee bean is

converted into the final product, whereas 95% of the processed material ends up as waste [109]. Companies have now discovered a way to convert coffee ground into a fabric that can be used in clothing. Up-cycling coffee beans can lead to a reduction of needed resources, while making use of coffee grounds that would otherwise be disposed of.

Bamboo - Bamboo is a versatile and fast-growing natural product, and the making of bamboo requires no pesticide or fertilizers [11]. Moreover, bamboo improves soil quality and can restore eroded soils. Despite these advantages, the production process for bamboo requires intensive use of chemicals. However, the end-product is generally more eco-friendly than conventional fabrics, such as cotton and polyester. Moreover, more environmentally friendly methods for processing the fabric are on the rise.

Eucalyptus - Fabrics made from eucalyptus trees are not widely used, but offer several benefits in terms of sustainable qualities. According to Parthiban et. al., eucalyptus trees are easy to grow in poor climate conditions, are fast-growing, and don't need irrigation or pesticides [11]. However, as with bamboo, the production process generally makes use of heavy chemicals. Nonetheless, eucalyptus is currently regarded as one of the most sustainable plant-based materials for fashion.

Organic wool - Wool is a material widely used in fashion, obtained from animals. When the current wool production improves, wool can be a sustainable option for fashion [11]. Aspects to consider are ethical living conditions of the sheep, and sustainable disposing of the manure. Moreover, chemical materials should not be used in the processing of wool. When these conditions for organic production are met, wool can be a sustainable material for fashion.

Hemp - Another fabric that is not yet widely adopted is the use of hemp. Harvesting hemp brings multiple benefits. One of the most important benefits is that hemp can be grown in most climates, and processed locally. It's fast-growing, and requires less land and water than cotton, for example [11]. Another crucial benefit is that hemp is organic, and therefore biodegradable [110].

The set-up of the exhibit

At the exhibit, fashion objects were replicated to evoke the imagination of being in a real fashion store. The exhibit consists of three main parts: a clothing rack, fitting rooms, and a stage where the installation is located (see figure 24). As this part was outside the scope of this research, it was installed by experienced construction workers. To resemble the interior of a fashion store, a robust stage, the clothing racks, two fitting rooms, dividing walls, a clothing scanner, and stylized information panels were installed.

The six sustainable materials were chosen for the final exhibit: bamboo,

eucalyptus, coffee grind, hemp, recycled PET bottles, and biological wool. The museum reached out to entrepreneurs in their network to gather a collection of sustainable fashion pieces that would be available for use during the exhibition. The clothing racks were installed, and one clothing item for each sustainable material was placed on the racks. The concept designer took off the regular labels, and replaced them with the labels for the exhibit. These contained a QR code and a sustainable hints. Each QR code could be scanned with a scanner next to the stage. When a visitor scans a piece of clothing, the system is triggered to start playing.

Figure 24: An overview of the exhibit, and a QR label with the hint 'Usually we throw away 98.8% of this material'

Guiding the interaction

To ensure that visitors understand what is expected of them, affordances were given through messages at each relevant touch point of the exhibit journey (see figure 25). This way, the installation is standalone and self-explanatory, without the need for supervision or instructions by a guide. The messages included instructions for the three main activities that the visitor should do: 1) grab a clothing piece from the rack and put it on in the fitting rooms, 2) walk onto the stage and scan the label, 3) start interacting with the system. As all three should be completed for an effective exhibit experience, these are explained through text panels that follow each other up. Moreover, affordances are added to encourage the visitors to continue discovering through messages like: 'Can you already guess what it is?', 'Do you know what I am made of yet?'. At the end there is an encouragement to try on another item, to find out more about other sustainable materials. This includes messages such as: 'Will you put on something else too?', and 'Let's try on something else!' The messages were written with the help of the project manager, who has experience with guiding visitors through exhibits.

Figure 25: Panel with instructions (left), and the stage with QR instructions and pink spot as location affordance (right)

Educational content

As discussed in section 5.1, the employees considered it important to include a sufficient educational message in the experience. In the design of the installation, the educational value is added providing the sustainable characteristics of the materials compared to conventional materials. For this reason, insights were gathered about each sustainable material, which were transformed into interesting and digestible pieces of educational content. As the sentences needed to fit onto the visitors' bodies, they were relatively concise. Also, the wording should not be too advanced, as the projected texts should be understandable for children aged 6 years and above.

The project manager and concept designer wrote the sentences, as they were qualified and experienced to make educational content. This resulted in the educational messages for the on-body projections in Table 2 below. The first column is the hint on the label for each material, which is aimed to evoke the visitors' curiosity to further find out what the material is. Then, three sustainable benefits for each material are listed, as well as one drawback in order to present a more complete picture. These would then be projected onto the shirt of the visitor when they participate in the exhibit.

Table 2: Sustainable messages for each material

	Hint on label	Sustainable text 1	Sustainable text 2	Sustainable text 3	Sustainable text 4
Eucalyptus	This clothing piece is grown in the woods	I am a soft and subtle fabric	This material is super strong	With me, you can exercise very well	The production still uses lots of energy

Bamboo	From this material, you can also build houses	I grow without use of pesticides	I absorb loads of CO2	I grow very quickly	In the factory, chemicals are still needed during processing
Hemp	This material is usually grown in the Netherlands	I grow very fast	I grow without use of pesticides	I breathe and absorb moisture	This material is somewhat on the rough side
PET bottles	For one jacket, you need around 14 of these items	Because of me there is less waste	I need less natural resources	Less water is needed to make me	When washing me, micro plastics are still released
Wool	This material needs grass to grow	I am warm in winter, cool in summer	I last a very long time	You don't have to wash me as often	Loads of land is needed for sustainable production
Coffee beans	Usually, we throw away 98.8% of this material	With me you can save valuable resources	I don't get dirty very quickly	You don't have to wash me as often	Usually, we still mix this material with cotton

Sensory attributes

To ensure sufficient sensory stimulation, multiple visual, and auditory features have been added to the installation. These features are aimed to create an immersive space for the visitors' senses. For example, when the visitor is standing on the stage, they are immersed by background scenery from where the material originates (see figure 26). For the visual content, video footage that is rich in colors and details was chosen. For example, for the fabric made of wool, a video is used of sheep standing in a meadow. In order to not immediately give away the material, the scenery starts out blurry, and becomes sharper as the visitor continues the challenge. Meanwhile, each scenery is enriched with sound effects that are associated with the sustainable materials. For example, for the coffee bean material, sounds are added that imitate coffee being grinded, poured, and drank from a cup. Moreover, background music has been added that are associated with the sustainable materials. Jazzy tunes typical for a cafe are chosen for the coffee beans, for example.

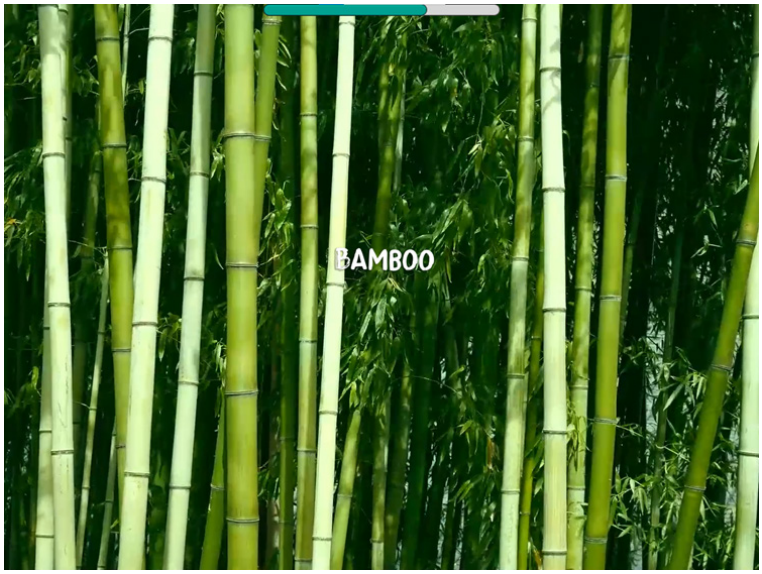


Figure 26: Background of the stage for clothing item bamboo

Voice-over

Next, it was decided to implement a voice-over for the auditory content. Visitors with impaired vision would still be able to learn at the exhibit. At the same time, people with a hearing disability are better supported by the visual content. This way, the main educational content would be accessible both through auditory, as well as through visual channels. This multi sensory approach is not only used for a more immersive experience, but it makes the exhibit more accessible for a wide range of visitors. It also enables younger illiterate children to learn about sustainable clothing. As the general public of the museum consists equally of native and foreign visitors, the voice-over should be available in both English and Dutch. To realize a sufficient level of sound quality, together with the project manager it was decided to arrange a professional voice-over in both languages.

6.2 System development

Development environment

The software for the installation was written in Unity (see figure 27). This decision was based on several reasons. First, it is the main software environment in which the other museum applications are written as well. This way, other software engineers are familiar with the program and can easier update it in the future. Second, Unity has a user-friendly interface that contains an intuitive hierarchy for organizing scripts, game objects, and media elements. It can relatively quickly be learned and is supported by a large community of developers. Software development kits (SDK) are available for a wide range of projects in Unity. Finally,

it is a widely used tool for the development of museum installations.

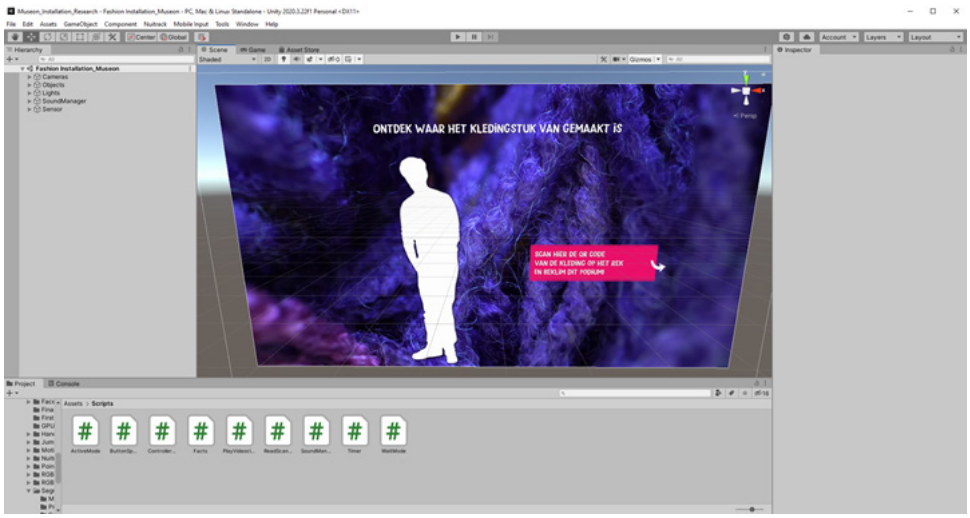


Figure 27: Development of the installation in Unity

QR scanner

Scanning the clothing is a hands-on interaction that should enhance the sense of being in a clothing store. For the exhibit, a QR scanner was placed next to the stage. The wire moves behind the back of the stage, and the scanner is locked into a holder to lower the chances of breaking. A unique string for each label is read from the QR scanner to detect which sustainable material should be played, as well as the language (e.g. 'EUCALYPTUS_ENG'). The first part of the string was then stripped to update the sustainable material, and the last part of the string was saved as the language. This way, the right sequence of elements is triggered when visitors scan the clothing.

Projections

Next, the projector BenQ - TH682ST was acquired for this study. This is a projector with 7000 lumen, which was deemed necessary for the installation. Another benefit is that it is a short throw beamer. The reasoning behind this choice was two-fold. First, a short-throw beamer would decrease the risks of eye strain, as it is placed far from eyesight. Second, the projector would not block the view of the visitor, and hence be less obtrusive for the experience. For this exploratory-oriented study it was assumed that one projector would be sufficient. The projector was placed onto the ceiling by the construction workers, who also ensured to tuck away the wires neatly (see figure 28). The calibration of the projector was done by using key stone corrections and color adjustments in the settings of the projector.

Generally, projection-based technology onto objects makes use of projection-mapping techniques. With this technique, a digitalized model of the object is used to create the illusion that the projections are placed onto the object. However, much

more advanced techniques are generally used when projecting onto dynamically moving bodies in real-time [81]. To avoid latency of the projections, these are often accompanied by pose estimation software. However, in the initial tests it was found that simple flat projections onto a body resulted in readable texts. This is because the front of a body is relatively flat, and low in irregularities. Even on partially wrinkled clothing, the display was sufficiently readable. To save time for the exploration on visitors, it was decided to continue the development without use of advanced mesh algorithms, such as done by Baroya [95].

Figure 28: The projector installed onto the ceiling

Body tracking

To follow the movements of the visitors, body tracking should be included. As with most studies, a depth sensor was acquired to enable body tracking. The sensor that was purchased was the Orbbec sensor, which allowed for a detection range up to 8 meters. Next, the placement was decided. The sensor could be placed next to the projector, but the distorted angle would complicate the detection of human figures. Therefore, the front of the stage was chosen as an alternative. Unfortunately, with this setup it could not be avoided that bypassing visitors would accidentally block the sensor. During the remaining of the study, the visitors will be requested not to step in front of the sensor during the interactions. The sensor was placed three meters in front of the stage, which produced sufficiently accurate readings. The hardware installer ensured a robust installation of the sensor in one of the building blocks for the exhibition.

As the body tracking technology is not the novel feature of this research, a

library was sought that includes body tracking software. Nuitrack was a software library that fit the requirements of this study, as it is compatible with Unity and produced good results during initial testing. The kit is a software package utilizing a machine learning algorithm. When the software detects a user, it produces a 'user skeleton'. In total, the position of 16 body joints is estimated and saved as a 3D vector. For this project, only the hands and the chest area of the user needed to be detected, so the remaining joints were disabled. To show visitors the position of their hands, two hand objects were placed onto the hand joints of the user. The projected text followed the movements of the visitor by placing it onto the center of the users' chest joint (see figure 29).

Figure 29: Texts projected onto the body

The 'Hook'

As explained by Csikszentmihalyi [36], exhibits should contain a hook to evoke the curiosity of visitors. This is the initial stimulation to enter the exhibit experience. For this exhibit, an silhouette of a human was added as the hook, which was retrieved from stock footage (see figure 30). The silhouette is animated in a loop, and has the size of a real human, in order to attract attention. As the silhouette is slowly swinging around, tapping its feet, and looking around, it indicates that it is waiting for something. This is aimed to enhance visitors'

curiosity, and indicates that something is about to happen. As the silhouette is projected as a life size person, it is assumed to catch visitors' attention. Next to the silhouette, an instruction is given on how visitors can activate the experience (e.g. by scanning their piece of clothing, and stepping onto the stage).

Figure 30: The life size silhouette moving and 'waiting' at the stage

Interactive challenge

For the interactive challenge of catching question marks, an algorithm was written. This assured that question marks appeared on the screen every few seconds. The visitors were then enabled to catch them with their hands. Their hands were captured by the body tracking feature, and by waving their hands around in mid-air, they could catch the question marks. Both the hand objects and the question mark objects were given a collision property. An algorithm was written that detects the collision of both objects. When this happens, the question mark object is destroyed and the next sustainable message is triggered. The question marks appear in randomly in one of the six appointed locations on the side of the visitor (see figure 31). By not placing the question marks too high, it is ensured that they are reachable for smaller children.

The installation followed a predefined sequence. Once the QR code was triggered, a sequence followed in which the visitor was given a short explanation on how to interact with the system. Then a sequence followed in which the background music, background video and sound effects start playing. During this

sequence, the question marks start appearing. Every time a question mark is caught, the next sustainable message is projected as a text onto the visitors' body. Moreover, a predefined timer was included at the request of the museum. This would be beneficial for situations in which a visitor cannot manage to progress. After 20 seconds, the next sustainable fact is displayed. This duration gives visitors a sufficient amount of time to complete the task, while ensuring that they do not get stuck. When the maximum time of 75 seconds passes, the sequence ends and the system goes back into the waiting mode.

Figure 31: Catching the question marks through hand detection

Mirror setup

A mirror was added to the installation, as it would allow visitors to view the effect of the projections onto themselves. As the content consist of text messages, one challenge arose. Due to the reflection, the texts will be mirrored for the viewer. This would make it more difficult for the visitors to read the messages through the mirror. One of the found solutions was to revert the text, so that it becomes normally readable in the mirror. However, this decisive solution was not favored, as it 'forces' visitors to look into the mirror. Rather, the mirror should be an additional support to view the on-body projections. With the choice for the latter, it would be anticipated that visitor might be stimulated to decipher the text with the help of by standing visitors. This could in turn increase the social value

of the learning experience. For these reasons, it was decided to leave the text normally, and continue with the trade-off of having reflected text in the mirror. For a visual reference, see figure 32.

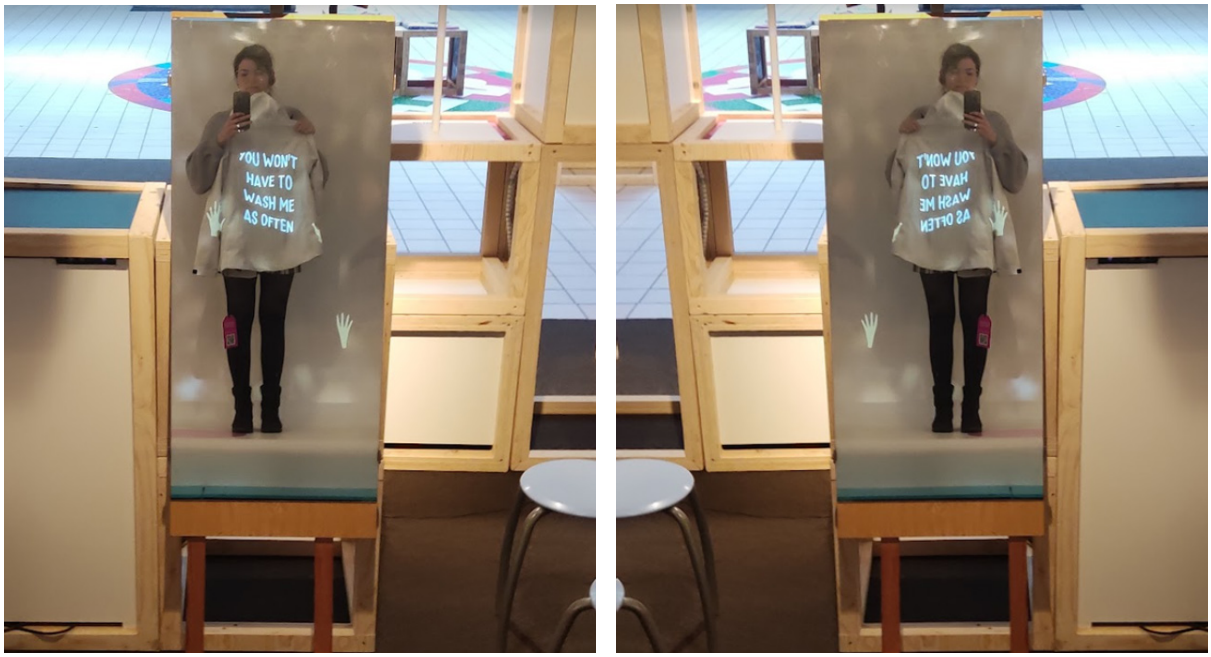


Figure 32: The on-body projections through a mirror (left: forcing, right: supporting)

Section 4

Exploration

7 Testing

In the previous chapter, it is described how the installation was installed in the museum. The installation could then be employed to serve the research gap, which was to study the influence of the on-body projections on the learning opportunity. This is explored through qualitative and quantitative user studies. This chapter concludes with a discussion of the findings in this study, and its relevance for future work.

7.1 The evaluation study

The study will include a comparison between two experimental conditions. In one, the exhibit content is displayed as on-body projections are present, and in the other, the exhibit content is displayed onto a flat surface. This way, a deeper understanding can be gained on how the on-body projections feature contributes to the emotional impact of the exhibit.

Parts of the evaluation

Emotional effects - This qualitative study will be an exploration into the emotional impact of on-body projections. Due to suggestions in previous works (see section 3.3), it is hypothesized that on-body projections might enhance the perceived emotional connection with the exhibit content. Enhancing the emotional impact of exhibits is crucial for effective learning about sustainable development [16, 22]. Therefore, this is an exploratory study to gain a deeper understanding of the emotional effects of on-body projections in the museum exhibit. A specific investigation will be done on how the relationship with the exhibit content changes when projecting the content onto visitors' bodies. Additionally, scores for the IOS scale are reviewed, as an additional method to understand peoples' sense of connection with the exhibit content. The visitors will interact with the installation, after which they join a session in which they discuss their experiences. The following sub-question will be answered:

"How do the on-body projections affect the visitors' emotional experience with the exhibit content?"

Exhibit evaluation - For the educative goals of the assignment, it is equally important to understand whether a learning opportunity has been effectively

enabled in the exhibit. When an exhibit stimulates the visitors' experience on affective, intellectual, and sensory levels, it sets the right circumstances for a meaningful learning opportunity [36]. Whether an effective learning opportunity has been enabled, is evaluated by a quantitative evaluation with the MES (see chapter 3.4) [9]. The scale evaluates to what extent a successful visitor experience has been established through four variables on intrinsic motivators. These were regarded to be most closely linked to the motivating attributes in the learning framework [36]. In the same study, it is quantified how the on-body feature influences the impact of the exhibit. This is again done through a comparison with a system without on-body projections. This way, the extent that on-body projections contribute to the impact of the exhibit can be quantified. The following sub-question will be answered:

"How successful is the on-body exhibit in establishing a meaningful learning experience?"

Setup for the conditions

The research in this thesis is divided into two conditions (see figure 33). To be able to understand the contribution of the on-body projections separately, a second condition without on-body projections was established. In the first condition, visitors interact with the system that includes on-body projections. One visitor stands on the stage, where projected content is displayed on top of the sustainable clothing that they are wearing. In the second condition, visitors interact with the system without on-body projections. Instead, the projected content is displayed onto the background of the stage, as if it were a regular flat screen (from here on referred to as on-screen projections for clarity). This setup required the least adaptations in the design of the installation, and would therefore closest resemble a baseline.

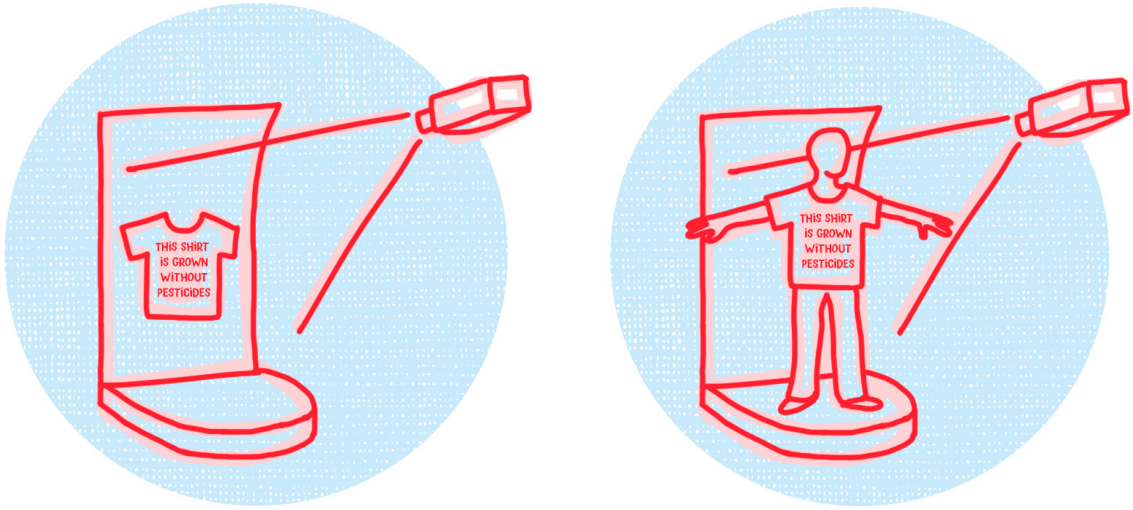


Figure 33: On-body versus on-screen projections setup (concept)

Figure 34: On-body versus on-screen projections setup (execution)

Limitations of the study setup

Ideally, the exact same setup is established for both experiment conditions, with only the on-body projections as a differencing factor. There were unavoidable differences in the study setup that might influence the study outcomes. In this chapter, a recap is given from the concessions that have been made in the study conditions.

Perspective visitor - The visitor is required to step off the stage in the second condition, to ensure that the text is not projected onto them. In the on-body condition, the visitor is standing onto the stage, the content is literally placed onto their bodies. In the on-screen condition, visitors are requested to stand in

front of the stage, to be able to fully view the content. This results in an opposite viewpoint, and the effects are observed from a slightly different distance (see figure 34). However, when assuming that the visitors will use the mirror to observe the content, the observation distance is smaller for the on-screen condition. To minimize these differences in experience, the visitors are asked to stand as close to the stage as possible to avoid influence of their position change. Moreover, the visitors are requested to solely assess the different information displays, and not their position in the experiment.

Wearing the clothes - Moreover, it was observed that not all visitors wanted to put on the clothes from the racks during the exhibit experience. This was due to several reasons. There were only one size for each piece on the rack, which made them unsuitable for all visitors to wear. Moreover, some visitors commented on the heat in the museum being a reason for not wanting to put on the clothing. As an alternative , the visitors were requested to hold up the shirt and drape it onto the front of their body, as if they were looking how it would fit them. This was considered as the closest alternative to letting visitors wear the pieces. Moreover, the installation contained different clothing pieces on the racks. During the experiments, visitors were asked to take a piece of clothing from the racks and wear it or drape it onto themselves during the experience. They were not specified which piece of clothing to pick from the racks. The different pieces might have resulted in different experiences between the visitors. However, it is not considered likely that this affected the comparison between the on-body and on-screen conditions, as the experience is similar in nature for all the clothing items. Moreover, the selection of the clothes was unlikely to be correlated with the experimental conditions.

Participants

Only participants over 12 years old were recruited, to ensure that the participants properly understood the questioning. Beside a minimum age, there were no restrictions on whom could participate. All questions and the system's language were both available in English and Dutch, to include visitors from all possible nationalities visiting the museum. This way, a diverse range of people could be included in the target group, to resemble the targeted public visiting the museum. All participants walking by were requested to take part in the study. For the experiment, one participant was instructed to interact with the system. The rest of their visitor group was asked to participate in the study by observing the experience, and joining the group interview session afterwards. As a motivation and reward for their work, each participant group received a pack of Easter eggs.

7.2 The qualitative study

Method

For this study, a within-participant experiment is conducted. This method is chosen as it requires less participants, and minimizes effects from characteristic differences between participants. The main objective of the study is to gain a deeper understanding of the emotional effect of on-body projections. The IOS scale was used to measure the visitors' emotional connection with the projections quantitatively. The scale mainly functioned a basis to gain a deeper understanding on 'why' participants gave a certain score. This helped to identify the underlaying factors that play a role in the emotional impact of the on-body projections. Only participating visitors were allowed to answer the IOS scale.

After that, the focus group took place. The first set of question were general, and were aimed to broadly explore the visitors' personal experience. Whatever they felt during the experience, they are able to express at this point. This is followed by a set of questions that dives deeper into the visitors' sense of connection with the exhibit content (see Appendix B). Here it is explored whether and how the on-body projections might have mediated this effect. Additionally, participants' were asked about their perception towards on-body projections as museum exhibit displays from a global perspective. For example, they were asked to what extent they thought this feature was useful and what kind of exhibits it might be used for. To account for learning influences, the order of the conditions was switched after every session. Considering the scope and time available in the assignment, 10 participants were recruited.

Setup

The study was held on a regular opening day for the museum on the weekend. The completion of the study took two days in total. Each session consisted of the participant interacting with the system in two different conditions. It was shortly explained that the objective is to study the effect of two different forms of displaying information. The participants were instructed where to stand for each experiment. They were then asked to take a piece of clothing from the rack, interact with the system, and pay attention to the display of the sustainable texts. They were able to ask questions at any point during the session, if something remained unclear.

The group interview took place after interactions with the system. The questions were aimed to understand the visitors' emotional experience with the projections more broadly, and the visitors' sense of connection between the virtual

content and themselves or the performing visitor. After each question, all visitors were asked to explain the 'why' behind their answer, to better understand how their experience was formed. When remarks were detected that could lead to unexpected findings, the visitor was asked to elaborate their answers. This gave a deeper understanding of how on-body projections were emotionally perceived by visitors. Each session took approximately 15 to 20 minutes, from the recruitment to the receiving of the gift.

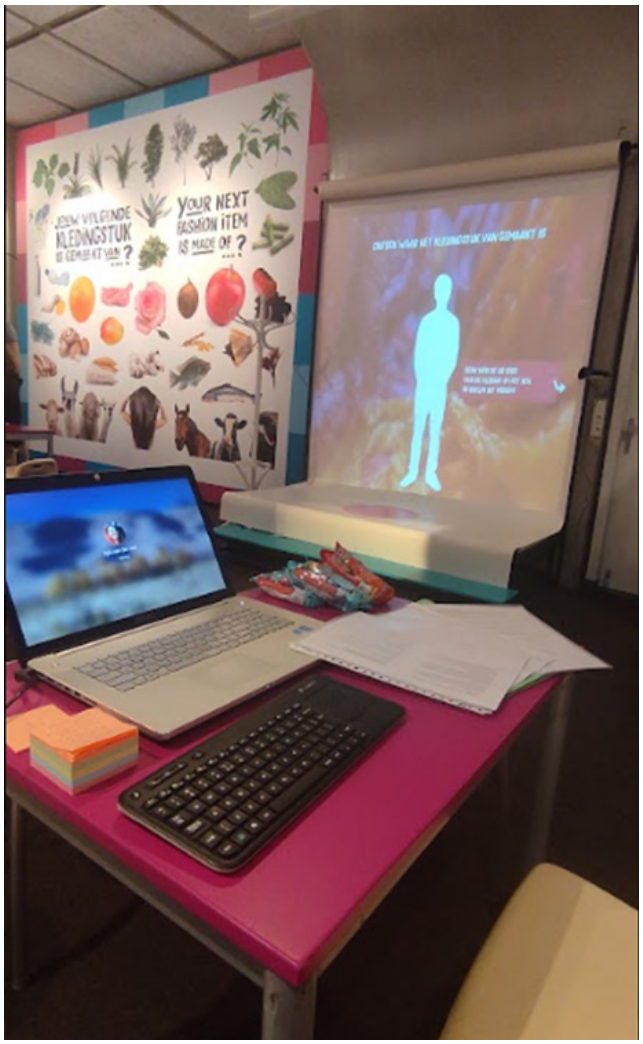


Figure 35: The researchers' setup during the experiments

Data collection

The researcher was present during the experiment, and the data was collected after each experiment (see figure 35). The performing visitor first filled in the IOS scale for each condition. After the whole experiment took place, the involved visitors in the group were asked to take a seat at the researcher's table. Basic demographics like age, gender, and group composition were recorded. Both bystanders and performers were invited to join the session, as either perspective

can provide valuable insights to the study. This group interview was supported by semi-structured questions, and each question was followed with a follow-up 'why' question. The answers were recorded through note-taking during the group interviews. After each session, five to ten minutes were taken to organize and store the data.

A total of 10 focus group interviews were held, with a total of 21 visitors joining. 10 of the participants had been performers on the stage, and 11 of the participants had acted as observers during the experiments. The performers were asked to fill in the IOS scale for their emotional connection with the virtual content. Both performers and observers answered the qualitative questions in the interviews, as both viewpoints were equally valuable.

Data analysis

After all the interviews were conducted, the data was imported in a data sheet. First, the answers from the qualitative interviews were thoroughly read. When everything was globally understood, the answers were given open code descriptions, to find similar themes throughout the data. The qualitative data, and coded descriptions can be found in Appendix C. These were analyzed again and put into similar categories, which resulted in a concise list of perceived emotional effects and usability criteria. These can be found in the next paragraph. Meaningful quotes were added to substantiate the findings.

7.3 Qualitative study: results

In this qualitative experiment, the contribution of on-body projections to the visitors' perceived emotional effects of the exhibit content was explored. The identified effects that played a role in the emotional impact were structured into similar categories. These are explained below.

Emotional effects

On-body preference - Initially, the visitors were asked which version of the projections they liked best, and for what reason. The preference for each type of projection was then counted. From the 21 participants of the focus group, 19 participants answered this preference question. 42% of the participants said they preferred the on-body projections compared to the on-screen projections. Notable is that another 32% of the participants reported a preference for the on-body projections, under the condition that they would be better able to read the text. These participants felt unable to read the text properly during their interaction, due to the reverted text through the mirror. Moreover, 5% of the participant clearly preferred the screen, and their main reasons were that the

text was easier to read, and did not cause as many distractions. Finally, 21% of the participants were indifferent with regards to their preference. There were no notable differences between the preference of the observing and performing visitors. The skewed preference towards the on-body condition could indicate that the on-body projections succeeded in enhancing the visitors' experience at the exhibit.

Higher sense of identification - Generally, participants perceived more personal involvement in the learning material in the on-body condition compared to the on-screen condition. Multiple participants stated that the message felt like it belonged to the person standing on the stage, and there was a higher sense of personal association with them. As one child stated: "*The text on my body felt more like it was part of me. If you read onto yourself that the material of your shirt saves more water, it is more about you doing that*". Such comments indicated participants felt more included in the exhibit content. However, a woman added: "*It feels more like it is a part of me, but it's still about a piece of clothing*", indicating that this participant felt a closer sense of association, but still sensed that it was a separate entity. Another woman explained: "*This information on your body draws your attention more, it feels like I wear it and it's about me*". An observing man noted that he did not associate the material with himself, but indicated an increased link between the content and his relative on the stage. "*I did not feel a connection with the text when you were on the stage, but that is because you were standing there. The relevance between you and the text became bigger. In all of a sudden it was like it was part of you*". This shows that the on-body projections also influence observers' perception of unity between their relatives on the stage and the virtual content.

This higher sense of identification was also seen when participants were asked to imagine the text containing a bad environmental message, such as "This shirt is made from fossil fuels that heat up the planet". Here it was found that almost all participants would rather view negative messages onto the screen. The participants generally did not want to get personally identified with unsustainable products. Additionally, most visitors did not prefer this negative form of awareness-raising on sustainable topics. Particularly children did not want to be associated with 'bad environmental products'. This is illustrated by the quote of one child: "*Something bad written onto yourself would not be nice. It would be like you are bad yourself. I want to be good for the planet, I bike a lot and want my clothes to be good too. So I'd rather watch it on the screen then*". One man stated: "*The If you see a message like that onto yourself, it becomes much more personal*". The avoidance of identification with bad messages onto the self could be another indicator of an increased sense of personal involvement with the exhibit content.

Higher sense of realism - On multiple occasions visitors reported that they felt the educational message had more of an realistic feel when projected onto their body. Many visitors experienced a higher sense of realness of the content displayed on their body than on the flat surface. As illustrated by what one man said: "*The experience with the information kind of became more 'real'.*" Another woman added: "*It really is as if you are 'wearing' the texts onto your shirt*". Moreover, the content being 'out' of a screen and into the real world, seemed to increase visitors' attention. As one woman explained: "*Otherwise it soon becomes one of the 300,000 screens I look at on a day.*" A child also empathized their preference for the on-body projections in comparison to the screen: "*I liked it on me. Because I look at screens very often. That is not good all the time. This is also better for your eyes*". This is followed-up by a man's comment: "*I see screens all the time every day, and I am trained to not really pay attention to them anymore*". The realism of the projections in turn seemed to increase visitors attention span, which is beneficial for museum exhibits promoting sustainable development. The results clearly indicated that the projections on the body made the information feel more real, which had a higher impact on the visitors emotionally.

Higher feelings of empathy - A surprising finding was that the higher sense of realness seemed to evoke higher feelings of empathy towards sustainable challenges. This is supported by the quote of one woman, who mentioned: "*It does make you stop and ponder, which is one of the goals of a museum. You are more confronted with the choices that you make, it makes you think about what you buy. On the screen, the issues are emotionally further away from you*". Another woman added: "*It (the on-body projections) made me empathize differently with the sustainable materials*". Moreover, some participants indicated that on-body projections are an effective tool to evoke empathic feelings for confrontational issues. In particular, because their higher sense of empathy seemed to evoke a self-reflective attitude. One man stated: "*The projections onto myself made me think, that happens much less with a screen.*" One woman stated: "*I'd pick the text onto your own body, that just seems to move you more, which is logical*". A man agreed to her statement with the notion: "*Yes, it just hits you harder I think*". These comments clearly indicate that the on-body projections can be effective in evoking empathy and a self-reflective attitude. This is ideal for awareness-raising topics that require people to adjust their behavior, such as sustainable development challenges. Moreover, suggestions were asked for other suitable use cases. Several interesting topics were suggested, such as raising awareness for the feelings of children that are bullied, the war in Ukraine, or breast cancer. Also, other environments were suggested, such as education in a classroom, or use in an educational campaign.

Willingness to learn - A notable finding was that participants regularly reported that they enjoyed the on-body projections, because it allowed them to discover information in new forms. One woman quoted: "*I am a teacher and these projections on your body are a really interesting way to learn about information. Some children are very visually oriented. This would work well for them*". Another woman added: "*I like this kind of stuff. It is somewhat different, and new. This can excite visitors to discover new things*". One woman asked her child: "*Which museum do you like more? The one where you sit and listen, or the one where you can explore and discover something new?*". She seemed to hint towards the latter, and the child agreed to her statement. The results indicate that the process of discovering new ways of learning is something that museum visitors appreciate in their museum visit. Additionally, it showcases that discovering how to handle a museum exhibit is by itself is seen as an engaging activity, and the on-body projections can trigger their excitement to learn new things. Finally, one woman explained: "*I like it this way, to discover new ways to learn. We will not forget the PET bottles very soon. Remembering the information will last longer this way*", indicating that novel forms of discovery might lead to longer retention of the learning material.

Advantages of a mirror - Almost all participants noted that they regarded the mirror as an essential addition to the on-body projections. During the experiments, generally all participants looked towards the mirror, instead of onto their own body. This is likely due to the difficulty of viewing the effect from looking down, or being able to read the messages. The majority of participants preferred to have the ability to view the effect on themselves in the mirror. One man explained that the mirror helps to avoid confusion: "*It's good that you can look into the mirror. Otherwise you keep looking around thinking what is supposed to happen?*". Another woman commented that the mirror fits well within the theme of the fashion area: "*A mirror is better than a screen, it fits better with the theme of the fashion area*". Despite the vast appreciation for a mirror, in multiple interviews potential adjustments were mentioned. Two men reported that the mirror was too narrow to see themselves and the question marks on the side properly. Also, one of the men explained that he would be more engaged if the mirror was closer to the stage. This would increase the immersive quality of the visual experience in the mirror.

Lack of social interactions - As described in the theoretical framework in paragraph 3.2, social interactions can be used to enhance learning opportunities [91]. The rationale of the installation design was to enable social interactions, but the experiments showed that it did not have the desired effect. The aim was that observing visitors would help the performer to read the text onto their bodies, as this would be difficult to do from their own perspective. However, there was little

social interaction between the participants during the sessions. In all experiments, the participant onto the stage followed the sequence of the system, with little help from the observing participant group. Multiple participants reflected on the newly discovered material, but only after they interacted with the system. For example, they stated their surprise, or asked what the other visitor thought. Despite the lack of the initially intended social interactions during the exhibit, the participants did not report this as an issue. Instead, the participants seemed to enjoy the exhibit experience fully by themselves, rather than using it for socializing with their visitor group. As one woman noted: "*The installation would have more of an impact without surrounding distractions. It would be nice to place it in an isolated space for example, with just you and the experience*". Although this might be impractical in a museum exhibition, it indicates that visitors did not see the lack of social interactions as an issue.

Usability findings

Readability problems - Despite the reported positive effects of the on-body projections, there were also complaints about the readability of the system. The majority of negative comments centered around readability issues with the reversed text in the mirror. In total, six participants reported that they were mainly unable to read the text because of the mirrored perspective. One men said: "*I was too occupied deciphering the message in the mirror, that I did not fully engage in what was happening*." One woman even noted that she considered the readability to be the biggest difference between the displays. Despite the readability problem, the system still enabled a different sensory experience. One woman mentioned: "*Even if it the text is reflected, it still does something. It is placed onto your own body, so that is a funny feeling"*. When normal text is viewed through a mirror, clearly it becomes mirrored as well. The rationale behind this choice was to provide an additional viewpoint for the visitor, not force them to look through it. However, many participants expressed that they would rather to be able to read the text as normal in the mirror. They expressed that readable text in the mirror would largely solve the readability difficulty, and lead to a more engaging experience.

Inaccuracy of body tracking - Additionally, some other factors were identified that could help to improve the accurate placement of the projections. The aimed effect was that the projections looked like a print onto the visitors' shirt, and would move along as they move. Moreover, in two experiments it was reported that the text did not always 'stick' onto the right place. Especially for shorter visitors such as small children, the tracking software did not always accurately track their body. In some occasions the text ended up in the wrong place when the visitor moved around. Furthermore, the text was too large for smaller visitors, which sometimes

resulted in an unnatural result. One woman argued: *"I would suggest to improve the height. On children, the projections end up on their head instead on the shirt. A different calibration for children and adults would be good. I had to move the shirt to get the text into the right spot"*. Finally, when the clothing was too wrinkled, the 'flat' projections did not work well. Although the above cases were rare, refining the details of the system would be beneficial for the impact of the experience. Therefore, improved body tracking, and implementation of projection-mapping techniques would be beneficial. For optimal impact of the on-body projections, it is advised to further improve some crucial details of the installation, such as automatic scaling, affordances on positioning the visitor, and placement of the sensor. These minor adjustments could help to increase the robustness of the on-body projections.

In the interviews, it was reported that the sensor did not always track peoples' gestures properly, which is linked to tracking issues in the point above. Visitors could not always compete the interactive challenge smoothly. Visitors that attempted to catch the question marks found that their gesture was regularly not detected. In some cases, it happened that observing visitors blocked the view of the sensor as they walked passed, which would make the body tracking fail. As the interactive challenge is the main part of the exhibit experience, this is a major issue that can largely influence the visitors' sense of engagement. As one woman stated: *"I see children hitting the stage wall, and nothing happens. I like the idea of the projections onto your body, but the system just has to work better."* Although the failure of the interactive challenge did not influence the effect of the on-body projections, it is highly recommended to further improve this feature for a more effective museum exhibit in general. As a solution, it could be chosen to replace the body tracking software with touch sensors for a more reliable interactive system, for example.

IOS scores

The IOS scale was used to measure the visitors' sense of connection with the virtual content. Moreover, the model functioned as a starting point for the qualitative discussion. In total 10 of the participants answered the IOS scale for both conditions. It should be noted that a proportion of the participants experienced difficulty reading the content in the on-body conditions, as described in section 7.3. This might have influenced their score-giving. Therefore, it was chosen to establish a hypothetical situation. The participants were asked what their answer would be, had they been able to read the text. Although these scores are for a hypothetical situation, it might contain valuable information on how the system is perceived without reading issues. Therefore, these adjusted scores were added to a new condition 'on-body projections without readability issues', which was used in further analysis of the results.

The IOS scores were imported in SPSS and the descriptive statistics were explored. The mean for the on-body projections without readability issues was highest (M = 4.7, S = 2.473), followed by the on-body projections without readability issues (M = 3.8, S = 1.101), and as last the on-screen projections (M = 2.10, S = 1.101) (see Table 3). The boxplot of the resulting scores can be found in Appendix D. The mean scores were translated back to the overlapping circles in the IOS scale for a visual comparison (see figure 37). To recreate the visual model, a linear relation was assumed between the Likert scores and the amount of overlap between the circles.

Table 3: Descriptive statistics experiments

	Text on-screen	Text on-body (without readability issues)	Text on-body (with readability issues)
Mean	2.10	4.7	3.80
Lower bound	1.31	2.881	1.990
Upper bound	2.89	6.419	5.610
Std. Deviation	1.101	2.473	2.530

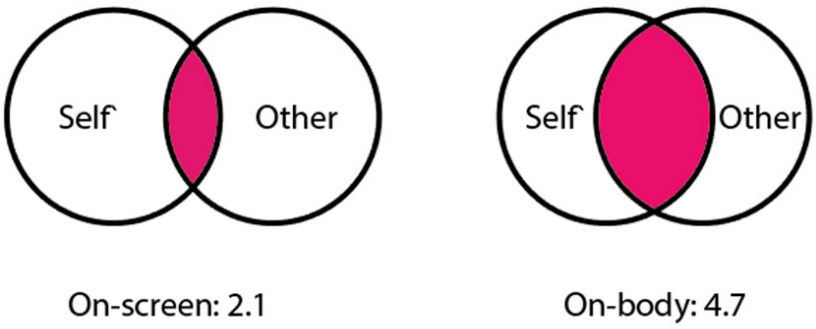


Figure 36: The means of on-screen and on-body (without readability issues) visualized in the IOS model

Finally, the results were statistically compared (see Table 4 and 5). As the scores did not comply with a normal distribution, as parametric assumptions were broken, the Wilcoxon Signed Rank Test was conducted on the scores. This is a non-parametric alternative of the paired T-test that is generally used for within-subject designs. The score of the on-screen projections was compared with both the score of the on-body projections with and without readability issues (N = 10). The significance was tested for a 95% CI. This resulted in an increase of the sense of connection, but this effect was non-significant (p = 0.058) for the on-body condition with readability issues, whereas the results were significant (p =

0.012) for the on-body condition without readability issues. Although no strong statistical inferences can be made from a hypothetical situation, the significant score differences could be an indication that visitors experience a higher sense of connection with projections onto their body, as opposed to projections on a screen.

Table 4: Wilcoxon-Test between on-body and on-screen projections (with readability issues)

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.[a,b]	Decision
1	The median of differences between Tekst op de muur and Tekst op lichaam (issues) equals 0.	Related-Samples Wilcoxon Signed Rank Test	.058	Retain the null hypothesis.

a. The significance level is .050.

b. Asymptotic significance is displayed.

Table 5: Wilcoxon-Test between on-body and on-screen projections (without readability issues)

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.[a,b]	Decision
1	The median of differences between Tekst op de muur and Tekst op lichaam equals 0.	Related-Samples Wilcoxon Signed Rank Test	.012	Reject the null hypothesis.

a. The significance level is .050.

b. Asymptotic significance is displayed.

Conclusion and iteration adjustments

The qualitative part of the study focused on exploring the emotional effect of the on-body projections in the museum installation. It provided insights into the visitors' degree of connection with the projections, and how the on-body feature influenced their scoring. In the qualitative analysis of this study, several emotional effects were seen. Participants reported that the on-body projections increased the emotional impact of the exhibit content in different ways. Amongst the most notable emotional effects were an increased sense of personal identification, an increased sense of realism, and increased empathy with the exhibit content. The on-body projections were perceived as an engaging new form of learning, and visitors perceived that it lead to a longer attention span and a higher self-reflective attitude. However, there were also crucial complications found during the study. A notable proportion of the visitors reported that they felt the on-body projections were too difficult to read, which could largely be attributed to the reverted texts in the mirror. Moreover, there were issues with the body tracking that caused experiential problems, such as the text not sticking in the right place, or the text disappearing for a few seconds.

Before continuing with the quantitative part of the study, an iteration was done in which adjustments to the system were made. Namely, minimizing negative

influential factors would make the next study results more reliable. Unfortunately, due to time and budget constraints, other issues, such as the accuracy of the body tracking, and placement of the sensor could not be looked into. Nonetheless, it was succeeded to resolve one of the major usability issues before the next study. This was the readability difficulty due to the reverted texts in the mirror. An alternative design was found in which the text would reverse and go back to normal every few seconds. This allows both the observers and the performers to sufficiently read the text, without forcing them to look in the mirror during the experience. The mirror was adjusted in width and height to ensure that the visitors could fully observe themselves and the rest of the exhibit. Furthermore, a solution was found for the failure of the gesture detection due to the body tracking accuracy. There was no time available to fix the gesture detection, but the problem could nonetheless be resolved by 'puppeteering' the interaction. A back-up button was added that allowed the researcher to imitate a successful gesture. This way, the visitor does not know that this feature does not fully work, and the interactive challenge can be completed as intended.

7.4 Quantitative study

Learning impact

The main objective of this study is to evaluate whether the on-body projection exhibit has enabled an effective learning opportunity. Secondary, the contribution of the on-body projections separately was evaluated. In particular, motivating visitors to engage with the exhibit is crucial in an effective learning process [36]. To what extent the exhibit managed to establish a meaningful learning opportunity was answered by means of the MES scale [9]. As described in section 3.4, the MES scale captures important components for a meaningful learning opportunity. It measures the visitors' learning experience at the exhibit through the variables Engagement, Meaningful experience, Knowledge/learning and Emotional connection on a 5-point Likert scale. Therefore, this scale was used to evaluate the impact of the exhibit, and the influence of the on-body projections on the results.

The sentences in the MES were slightly adapted to better fit the objectives of this study. This largely meant changing the wording in the questionnaire from 'the exhibition' to 'this exhibit'. It is not expected that this correction highly impacts the validity of the study results. Moreover, as most visitors speak native Dutch, it was decided to develop an additional Dutch questionnaire. This was done by translating the original MES scale in Google Translate, in order to generate unbiased sentences. To validate whether the translation was successful, the translated sentences were transformed back to English in the same program. This showed that the meaning

of the sentences remained roughly the same. Therefore, it was assumed that the adapted questionnaire could be used as it is intended. The adapted and translated questionnaires can be found in Appendix E.

Setup

The evaluation includes a comparison with on-screen projections, to be able to measure the influence of the on-body feature separately. This is done in a similar fashion as the first study, as described in section 7.1. The study was held on regular opening days in the museum during the weekend. In total, four days were needed to collect the study data. Each session started with asking the participant for their participation, and the objective of the study was explained. An instruction followed on the working of the installation, and what the participant had to do. They were then invited to interact with the installation in two different experiments, once with the on-body projections and once with the on-screen projections. After each condition, the participant was asked to fill in the MES scale, either on paper or on the laptop. They also filled in basic demographics such as their age, gender, and group composition. To avoid influence of potential learning effects, the order of the conditions was switched after each experiment.

Data collection

In total 16 participants interacted with the system and filled in the questionnaire. For this study, only visitors were recruited that interacted with the system, and observing visitors were excluded. Basic demographics like the visitors' age, gender, and group composition were noted. The researcher was present during the experiments, and participants could ask questions if anything was unclear to them. After each condition, the participant was requested to fill in the MES questionnaire. When the experiment finished, the participant was thanked for their time and given a small edible gift.

Data analysis

After all studies were held, the raw data was stored in a data sheet, and imported in SPSS version 28.0.1.0. The Likert items that belonged to the same variable in the MES scale were averaged for each sample, resulting in the variables Engagement, Meaningful Experience, Knowledge/Learning, and Emotional Connection. The averaged variables were then regarded as interval data. The variables were tested for a normal distribution by looking at the skewness, kurtosis, and Shapiro-Wilk significance in the descriptive statistics. With the results, a normal distribution was assumed for all variables. Then the assumptions for the Paired T-test were tested before performing the statistical analysis, such as using interval data, homogeneity of variances, and having a reasonably large sample size. Although the reasonably

large same size was debatable with only 16 participants, nonetheless it was decided that the analysis could help to build evidence for future meta-analysis. Moreover, independence of variables was assumed, as the experiments were conducted independently of each other. Therefore, the statistical analysis was continued. For more details on the normality distribution test and the acceptance of the assumptions, see Appendix F.

Furthermore, the Cronbach's Alpha was computed for the variables to understand the internal consistency of the items. This is a reliability test that validated whether the items in this dataset can be attributed to the same variable. The output for each variable can be reviewed in Appendix G. As a guideline for the reliability test, generally the Chronbach's Alpha should be >0.70, or at least >0.50 for less than 10 items per variable [111]. The Cronbach's Alpha for Engagement, Meaningful Experience, Knowledge/Learning, and Emotional Connection for the on-screen condition were 0.855, 0.582, 0.888, 0.863, and the on-body condition were 0.819, 0.828, 0.737, 0.793. Therefore, all variables confirmed to the test statistics, with which the consistency of the items was assumed.

7.5 Quantitative study: results

MES results on-body versus on-screen

The Paired Samples T-Test (N = 16) was conducted on all variables from the MES scale, comparing the on-body condition to the on-screen condition. In the T-Test a 95% CI was used. The experiments for the on-body condition resulted in a mean of 4.175, 3.859, 4.000, 3.250 for the Engagement, Meaningful Experience, Knowledge/Learning and Emotional Connection variables, respectively. For the on-screen experiments, the variables had a mean of 3.975, 3.953, 4.063, and 3.250. The Engagement variable significantly increased for the on-body experiments, with a resulting p = 0.021, and t(15) = 2.582 (see figure 41). The Meaningful Experience, Knowledge/Learning, and Emotional Connection resulted in a p = 0.287, 0.656, and 1.000, and t(15) = -1.103, -0.455, 0.000, respectively, which were non-significant results.

Table 6: Means and standard deviations for on-body and on-screen experiment

Variable	On-body	On-screen
Engagement	M = 4.175, S = 0.597	M = 3.975, S = 0.593
Meaningful Experience	M = 3.859, S = 0.619	M = 3.953, S = 0.510
Knowledge/Learning	M = 4.000, S = 0.495	M = 4.063, S = 0.635
Emotional Connection	M = 3.250, S = 0.736	M = 3.250, S = 0.760

Table 7: Paired Samples T-Test

Variable pair	95% CI	t	two-sided p
Engagement	[0.035, 0.365]	2.582	0.021
Meaningful Experience	[-0.275, 0.087]	-1.103	0.287
Knowledge/Learning	[-0.356, 0.321]	-0.455	0.656
Emotional Connection	[0.148, -0.316]	0.000	1.000

Bonferroni Correction

The amount of variables can increase the statistical chance of finding a false-positive significant result due to a family-wise error rate. With four variables, the chance of a false-positive is 18.5%. Therefore, a Bonferroni Correction was conducted. The p-value would be divided by the amount of variables, resulting in a required p-value of 0.0125. Thus, as the engagement variable 0.021 is > 0.0125, this would mean that the result is non-significant when a Bonferroni Correction is applied. However, it should be noted that the method has its own disadvantages in its strictness [112]. For example, the Bonferroni Correction corrects the chance of a false-positive, but compromises with an increased chance of false-negative results. This decreases the chance of finding an effect that is actually there. Nonetheless, the possible non-significant difference for engagement after a Bonferonni Correction should be kept in mind when interpreting the results.

Issues with body-tracking

While most of the usability issues from the first study were eliminated, some issues remained that might have negatively affected the scoring. A major issue was that during some of the experiments, the body tracking feature did not function as expected. In some cases visitors were not detected as accurately as others, which resulted in the text being placed partly off of their body, or not accurately following their movements. These differences in tracking accuracy for different visitors are assumed to be due to visual differences, such as clothing, body size or the changing of the light throughout the day. Moreover, it could not be avoided that observing visitors, particularly children, ran in front of the sensor during some of the experiments. As the body tracking had to be re-calibrated, this resulted in a misplacement of the text for several seconds. These observations were noticed in some of the experiments, and it reasonably could have negatively influenced the visitors' scoring of the MES for the on-body experiments. This could have decreased the scores for the on-body projections in the statistical analysis. This should be kept in mind when interpreting the results.

8 Discussion

This work produced three contributions for research in the form of a theoretical framework, design lessons, and an exploratory study. In the following section, the findings, the shortcomings and the potential of the study are discussed.

8.1 Theoretical framework

In the beginning of this thesis, a theoretical framework was build to better understand how to design effective museum installations for sustainable development. Here, it is summarized how this work relates to the global principles of the literature work, and how the guidelines are incorporated.

Exhibits for sustainable development - The main design lesson for developing exhibits for sustainable development is to focus on a positive outlook. In this work, the emphasis was therefore placed on communicating on a hopeful future. This was the goal of the exhibition at Museon, and was in line with the recommendations in research. Generally, this positive communication strategy seemed to work well. In this work, the strategy was chosen to assess the key components for a meaningful learning experience, as it can be notoriously difficult to assess exhibit impact on visitors in terms of the learning outcomes. Therefore, instead of aiming to evaluate specific learning outcomes, the aim was set on setting the right circumstances, for a learning opportunity to arise. Moreover, multiple studies showed the strongest predictor for learning impact was the arousal of emotions in exhibits [16, 22]. Therefore, establishing an emotional connection within the exhibit became the driving force of this work. The aim for an emotional stimulation was further investigated through the design direction, and the evaluation studies with the on-body projection installation.

Museum learning framework - In this design work, setting the right circumstances was done by following the principles of the framework for *museum learning* by Csikszentmihalyi [36]. The framework provided useful principles for establishing effective learning opportunities through museum exhibits. In particular, the importance to motivate visitors in a free-choice learning setting, through sensory, emotional and intellectual elements, and an engaging challenge, were understood to be of crucial importance. Therefore, in the design of the installation, inspiration was taken from this viewpoint. For example, visitors received educational hints and information throughout the experience for mental stimulation. For sensory stimulation, visitors can inspect, touch, and try out the

clothing themselves, and background music and visuals were added to the stage. Most importantly, on-body projections were integrated to establish an emotional connection with the exhibit content. The framework was regarded as a highly useful guideline for building exhibits for immersive learning opportunities.

8.2 Design lessons

Several design lessons were drawn throughout the research process that could be insightful for future researchers. These are explained below in separate points.

Which design lessons can be drawn when utilizing visitors' bodies as a museum exhibit display?

Suitability of the concept - The suitability of the concept for on-body projections is an important point to consider. This relation between the physical object and the projections is a unique point to consider [92]. Although a strong link is not always necessary, during the brainstorm session, it was discovered that not all ideas can be easily translated to on-body projections. For example, one idea that was discussed was the implementation of a quiz, where visitors have to give their answer to an A or B question. However, converting this idea to the core of on-body projections in a meaningful way seemed problematic. It is advised that the projections serve a meaningful purpose in a concept, instead of merely functioning as a decorative addition. Thus, in order to be meaningful, the connection between the content and the body should be at the core of an idea, so that the body as a display is the primary part of the experience. In this work, this is found in the projections being a symbolic textual print on the shirts, which is often seen in fashion. As the sustainable clothing items were predetermined, the concept had to be 'wrapped' around it. In similar future cases where the content is predetermined, it is advised to ideate with a similar mindset. Falck and Halskov can be consulted for utilizing other forms of content for on-body projections, such as film, video, graphics, text [92]. Their focus is on projection-based installations in general, so it would be interesting to further explore how their insights apply to on-body projections.

Placement of the setup - The placement of the sensor, projector, and mirror can largely determine the usability of the installation. This point was not previously mentioned in other reviewed works, but it did have important consequences. For example, in this work the sensor was placed in front of the stage. It needed to be installed in a wooden framework that was part of the architecture, in order to conceal the sensor adequately. However, the placement resulted in a two meter gap between the sensor and the stage. Although visitors were warned not to walk in front of the sensor during the studies, this behavior can not be ensured

when the installation is unattended by supervisors. Moreover, it was challenging to find suitable affordances that would retain visitors from walking in that area, while the experience is taking place. Ideas from placing tape on the ground to signal the presence of the somewhat hidden sensor, to giving visitors an additional instruction through the voice-over were discussed. However, each would require visitors to do an extra action to ensure the smoothness of the experience. Risking that visitors will walk in front of the sensor will also decrease the usability of the installation. Thus, it was found that a suitable placement for the setup is crucial, preferable unobtrusive to the experience. Compared to the sensor, the projector was positioned in a more usability-friendly place. The projector was placed on top of the ceiling, so it would not be as much of a challenge to redirect visitors. This choice was more successful, as visitors would not be able to walk in front of the projector, or break it. However, for the sensor, this placement could bring other challenges, in terms of what a camera angle distortion might do to the accuracy of the body-tracking software. During this work, it was assumed that body tracking is most effective when bodies are captured from straight ahead, rather than from skewed angles upwards or downwards. This situation should be tested for further consolidation.

Surface color and lightning - Consider the color and lightning conditions of the environment. During ideation, the projections were found to be strongly affected by the color of the surface object and the lightning in the room. This fits the theory on a need for contrast between design elements [63]. In this case study, the bright environments caused a more dull and weaker visual experience than preferred. It was seen that imagery or video footage on a red shirt highly absorbed the color, resulting in an unrecognizable image. Similarly, white text transformed into a vivid red color on a red shirt. Since it did not affect the recognizability of the specific text content in this project, it was not a problem. When it is unavoidable to include saturated objects in a project, content like text messages are suitable solutions, as they do not rely on colors to be recognizable. Otherwise, Siegl et. al. can be reviewed on how to add luminance optimization algorithms that could be looked into as well [6]. Such tools can help to override the initial colors of the objects, or even remove patterns on the physical object. In future studies, it is nonetheless advisable to establish a sufficiently dark environment and unsaturated physical objects, as the maximum capabilities of projections can then be fully appreciated.

Designing affordable on-body projection systems - The assignment in this thesis provided an excellent opportunity to study what emotional impact on-body projections would have in a museum exhibit on sustainable development. From the literature work, it was found that working with projections can be complicated. The required techniques become increasingly harder with dynamic objects that do

not have a predefined shape, for example human bodies. With such prerequisites, usually novel and advanced on-body systems are required, such as pose estimation prediction or projection-mapping techniques [90, 95, 101]. However, this is currently still under progress and not widely used outside academics. However, in this work it is shown that an on-body system can be built based on body-tracking alone. Apart from issues with the accuracy of the body-tracking that can be resolved, this setup provided convincing visual effects for the purpose of this study. In particular, the study results have shown that even with rather simple setup for the on-body projections, a perceived emotional impact on visitors can be obtained. Therefore, body-tracking could be used for implementing low-budget on-body projections in museum exhibits. This can be used on the frontal or back part of the body, for example, which are sufficiently 'flat' areas for convincing visual results. Although it compromises the possibility to do a bodily projection from all angles, it can be particularly interesting for educational institutions without a high budget or technical resources.

Use of a mirror - During the first study, the use of a mirror was a highly appreciated addition to on-body projections. As this was a determining factor in the effectiveness of the display, this is mentioned separately. The majority of participants reported that they either appreciated the mirror, or even ought it to be a necessary addition for the experience. However, the use of a mirror in combination with textual content brings its own considerations. In this work, visitors preferred to read text through the mirror, which implicates that the text should be reversed in the software. As visitors expressed their preference to read the text in the mirror, reversed text was implemented in the next iteration. To allow visitors and observers to enjoy the effect from both perspectives, it was chosen to alternate reversing the text every few seconds. This seemed to be effective in this study, but it is not known whether it might cause visual overload. In conclusion, the reversion of text remains a choice that mostly depends on the purpose of the installation.

Nonetheless, the preference of a mirror for a more immersive experience remained evident. After the experiments took place, multiple visitors came back voluntarily, to make the importance of the mirror known. Visitors highly enjoyed to view the projections onto themselves through the mirror, and even perceived it as a critical element to the experience. Through the mirror, they were able to fully absorb the visual effects, which was more challenging from the perspective of looking down onto their own bodies. Furthermore, visitors suggested to place it closely in front of them, to maximize the immersive effect of a mirror. Also, the width and height of the mirror should be sufficient, so that the full experience can be observed. As the enjoyment of viewing on-body projections through a mirror has not previously been observed in research, this is an important discovery that

is made in this study. Future studies are recommended to further investigate the use of a mirror in on-body projection exhibits. It could also be compared to other reflective mediums, such as a live camera, or pictures after the experience.

Wearing the clothes - Despite the focus on on-body projections, there were other exhibit features that could be interesting for further investigation. For example, the feature that visitors are prompted to pick out the sustainable clothes from a rack and try them out personally. This is a level of interaction that is not widely adopted in museum exhibits, and could therefore be interesting for research. Little known about the effect of wearing sustainable clothing items on the visitors' learning process, for example. Additionally, it is unknown to what extent the wearing of clothes might have mediated the emotional effect of the on-body projections. However, the on-body projections were tested as separate as possible from the rest of the installation. A similar experiment could be conducted, where the wearing of the clothing is separated from the rest of the visitor experience. It is hypothesized that such a bodily interaction might positively contribute to the immersiveness of museum exhibits, but currently this is not yet confirmed. For further exploration on this topic, more research is required.

8.3 Emotional effects

In the first evaluation study, the emotional effects of on-body projections were explored in more depth, compared to regular surface projections. The discovered effects are categorized and summarized below.

3. How do the on-body projections affect visitors' emotional experience with the exhibit content?

Emotional connection - In the evaluation study, the IOS scale was used to evaluate visitors' sense of emotional connection with the exhibit content. The hypothesis was that the emotional connection with the exhibit content would increase through on-body projections, and this was seen in the experiment. In the actual condition, there was no significant increase observed. However, as there were many complaints about the visitors' inability to read the text, a hypothetical situation was established. The visitors were questioned what their answered would be, in the assumption that they would be able to read the text. The scores for that situation showed a significant increase in emotional connection with the exhibit content. However, the increase was thus only observed in a hypothetical condition. This limits the possibility to make strong statistical inferences, but it could nonetheless be an indication that visitors experience a higher sense of connection with exhibit content through projections onto their body, as opposed

to projections on a screen. If this is true, on-body projections can be highly useful in enhancing the emotional aspects of an exhibit experience. Further investigation is recommended for a more robust confirmation of the effects.

Increasing realism - After the development of the installation, the effect of on-body projections was assessed in two different studies. In both experiments, the system including on-body projections was compared to a condition without on-body projections. The first study consisted of qualitative interviews, where possible factors that contribute to emotional impact of on-body projections were identified. As described in the related work, one of the motives of the project was to establish technology that is better embedded in the museum environment. This study showed that on-body projections seem to accomplish this requirement. A trend was observed that participants perceived the projections as more realistic. In the qualitative study, multiple visitors reported that the on-body projections made the content feel more realistic than a conventional surface display. In the qualitative study, it was often stated that visitors feel exhausted by seeing screens throughout their day, and subconsciously, they do not really pay attention to them anymore. Visitors stated that this excessive use of screens, albeit with their own or the museums' devices, resulted in more numb feelings towards exhibit content. Instead, the on-body projections felt more grounded in the real environment, which succeeded to evoke their attention. Therefore, on-body projections were able to address a critical concern in research about the risk of distractive screens in museums [69, 77, 78, 79, 80, 81, 82]. Additionally, it confirms that on-body projections can fulfill the critical need for more seamless integration of technologies in museum exhibits [87, 88, 89].

Increasing self-reflection - Another observed theme was that visitors perceived the exhibit content to be more personal, when it was projected onto their bodies. The content mainly consisted of sustainable qualities of the fabrics. However, when projected onto a surface, this did not seem to evoke a sense of personal involvement. This changed when the sustainable messages were projected onto the visitors. In the study, it was found that visitors were more likely to associate the messages to themselves, or to their relatives onto the stage. The effect was also observed when visitors were questioned about bad sustainable messages. In that situation, all visitors preferred the messages to be shown on a screen, indicating that they rather avoid a personal association with negative messages. In turn, the increased sense of personal involvement seemed to evoke a self-reflective attitude. Indications were found that visitors started to think about their own shopping decisions, for example. Visitors noted that this critical thinking attitude happened much less in the experiment with regular screens. As self-reflection can be an important outcome for sustainable development education [16], on-body

projections in museum exhibits can offer high potential for increased self-reflection.

Increasing empathy - Furthermore, indications were found of increased feelings of empathy with the on-body projections, as opposed to the experiment with the screen projections. Visitors assessed their emotional feelings with the on-body projections, and stated they felt more sensitive towards the sustainable issues. In particular, their emotional concern towards the sustainable fabrics seemed to be addressed through increased feelings of empathy. The arousal of empathy can be highly desirable, particularly for the purpose of promoting sustainable development [25]. However, on the other side, visitors perceived the exhibit content as more confrontational. This can be controversial, as it is debatable whether making visitors feel confronted is an ethical choice. However, it was not observed that visitors perceived the increased confrontational feelings as a negative influence. Instead, it was reported as a positive outcome. Bodily projections might be a way to better ground people in reality during their museum visit, and give the exhibit content more emotional depth. If its done in an ethical way, on-body projections could be a way to open up visitors' feelings for the challenges in the world. This can be issues regarding sustainable development, but other awareness-raising issues were also suggested, such as education about health diseases, bullying in school, or countries at war.

Novel technology - Visitors reported that they generally preferred the on-body projections over the projections onto a regular screen. One of the reasons is that visitors regarded their encounter with a novel exhibit as an important aspect for their motivation to learn. The discovery of novel technology, and how it works, was appreciated as an exciting activity by itself. Multiple visitors stated that new forms of learning can help with memory retention of their exhibit experiences, meaning that the learning impact could be higher with on-body projections. Additonally, visitors stated that on-body projections could support people with a strong visual focus.

8.4 The learning opportunity

In the second evaluation study, evidence was sought for the effect of on-body projections on enabling a learning opportunity in the exhibit. This is evaluated by using the MES scale, which measured visitors' intellectual, meaningful, engaging, and emotional experience. The findings from the quantitative evaluation are discussed below.

4. To what extent is the on-body exhibit effective in terms of enabling a learning opportunity?

Visitor learning - The second study consisted of a quantitative evaluation of the installation. It was investigated whether and to what extent the on-body projections enabled learning at the museum exhibit. Due to the free-choice learning environment, internal motivation is a crucial factor for enabling meaningful learning opportunities [36]. To measure whether a successful learning opportunity was enabled, the MES scale was used. The MES includes measurements for intrinsic motivators, such as engagement, emotional, intellectual stimulation, and whether their exhibit experience was meaningful. The scores for the on-body projection system for Engagement, Meaningful Experience, Knowledge/Learning and Emotional Connection variables, were 4.175, 3.859, 4.000, 3.250 on a 5-point Likert scale. Unfortunately, there are no standards for which scores should be achieved in order to call it a successful exhibit. Despite that, all numbers are above average, and are regarded to be on the fairly positive side of the scale. Thereby, it is assumed that the installation is sufficiently successful in obtaining the objectives of the museum.

Engagement - For academic relevance, the separate influence of the on-body projections on the learning opportunity was explored. This was achieved by comparing the resulting scores between the system including on-body projections and the system without on-body projections. In the latter condition, the exhibit content was projected onto a regular surface. A Paired T-Test analysis between the experiments showed a significant higher engagement with the on-body projections, with a p-value of 0.021. This result might be attributed to the finding in the first study, were visitors appreciated the discovery of novel technology was an engaging activity by itself. Increased engagement through novel technologies is mentioned by previous studies [38, 39, 73], which could also explain the result. However, the engagement variable might also be significant due to a possible family-wise error. With a Bonferroni Correction applied to the four variables, the result for engagement was not significant. However, the use of this method compromises with an decreased chance of finding a true result [112].

Nonetheless, the merely increased engagement variable was considered surprising. Due to the convincing results from the first study, it was expected that the variables emotional connection or meaningful experience would increase, whereas the results only showed significant increased engagement. This was unexpected, but perhaps due to essential improvements on the body-tracking feature. Inaccuracies of the body-tracking were observed in multiple of the user evaluations, which might have negatively influenced the visitors' scoring. Zheng's statement could be linked to this, stating that too complex novel technology can overwhelm visitors [42]. This could have been the case, when the body-tracking did not function as smoothly as intended. Therefore, the effect comparisons might

not be conclusive, as the impact of the on-body projections might actually be higher than reflected in the study results. In particular, improvements should be made on the reliability of the body tracking software for better placement of the text and recognition of the gestures. This needs to be addressed in future studies for a more valid evaluation.

8.5 Further recommendations

Museum Experience Scale (MES) - Although the principles of the framework by Csikszentmihalyi were utilized in the design of the installation [36], there was no evaluation scale included to measure whether enabling a learning opportunity was successful. Therefore, an alternative was sought. The Museum Experience Scale was chosen as the closest alternative to the framework [9], as it measures the visitors' learning opportunity through intrinsic motivators similar to the museum learning framework. It captures the exhibits' learning opportunity in terms of the visitors' perceived levels of engagement, intellectual, emotional, and meaningful experience during the exhibit experience. Moreover, it was the only experience scale tailored to museum environments. The choice was based on these major advantages, but there were also some disadvantages to the use of the scale. For example, factor loadings for some of the items were on the lower side. Moreover, the sensory attribute from the learning framework was not covered in the MES scale. Perhaps, there are additional methods required to measure the sensory attributes of an exhibit. Moreover, evidence might still be required to validate whether the MES scale is able to capture the principles in the learning framework. Despite these drawbacks, the MES scale was assumed to be the most suitable evaluation scale for measuring effective learning opportunities in exhibits, and shared most similarities with the learning framework.

Body-tracking accuracy - Additionally, critical improvements were found for a better utilization of the on-body projections in the exhibit. Unfortunately, due to limited time, some issues from the first study were left uncovered, in particular the occasional inaccurate placements of the text. In some experiments, the placement of the projections onto the visitors' bodies was considered insufficiently stable, which might have negatively influenced the visitor experience. In the experiments it was observed that the text was not always positioned in the right place. This is most likely due to the differences in visitor appearances, such as their height, shape, clothing, or colors. Moreover, the altering light throughout the day might have caused differences in accuracy on different times of the day. It would therefore be advised to optimize the accuracy of the body-tracking through more robust calibration, or find alternative software. Furthermore, for an optimal visitor experience, automatic scaling of the content could be added for children's

bodies, and a placement of the sensor that avoids bypassing visitors obtruding the experience. Optimizing these details will enhance the robustness of the projections, thereby maximizing the emotional benefits of the on-body projections.

Advancing on-body technology - As explained, in this study case, flat projections were utilized for the on-body display. This means that the mesh for the virtual content was a simple plane, rather than a three dimensional shape. This choice produced a sufficient system for exploring the impact of the on-body projections. However, as with most innovations, it is beneficial to keep improving the technique for more sophisticated experiences. Therefore, researchers looking for more sophisticated techniques could look into other works. For example, one paper by Hoang et. al. developed a skinning technique that binds a three dimensional mesh onto a skeleton, which allows for a more accurate dimensional translation of the content onto a dynamic surface [101]. Another technique that can be further explored is motion prediction, as utilized by Baroya, to minimize the time between recording the pose and projecting the content [95]. Reducing this lag will result in a more believable effect of the projections sticking onto the body, especially when the target person moves around. Finally, Natira et. al. developed a technique for mapping projections onto non-rigid surfaces, like fabrics [113]. Invisible infrared markers are placed to track the movements of the shirt. When it stretches, the print stretches as well. These techniques can potentially increase the visual impact of on-body projections, to keep inspiring visitors in their museum visits through novel technologies.

9 Conclusion

Museums are places where visitors become more deeply involved in educative topics through immersive exhibit experiences. Interactive technologies are increasingly used to provide visitors more engaging learning opportunities. Recently, a concern has grown for how interactive technologies in museums draw attention to virtual devices, and how this distracts visitors from real life experiences. Projection-based technologies are exceptional in this regard, as they merge virtual content with real life objects. This way, it provides opportunities to build a stronger connection between visitors and the learning material. This sparked an interest in the use of on-body projections for a museum exhibit on sustainable development.

The assignment

This project provided an opportunity to explore the use of on-body projections in the museum. This initiated from a request from Museon for an installation at their new exhibition called 'One Planet NOW!'. In particular, the installation would be destined for the fashion area, where visitors could discover and try out new sustainable fabrics in a replicated fashion store. Several studies emphasize the importance of establishing an emotional connection with the exhibit, in order to maximize the learning impact of sustainable topics [18, 24, 16, 27, 25]. Therefore, one of the main goals was to increase visitors' emotional connection with the exhibit content. The museum suggested to look into the use of projection-based technology, and after an investigation, on-body technology seemed suitable for the purpose of this study. Several researchers have argued the benefits of projection-based technology in terms of offering shared immersive experiences [84, 6, 5]. More importantly, two studies suggested that a deep sense of unity with virtual content can emerge when utilizing projection-based technology [7, 95]. However, the studies did not explore why on-body projections alter the emotional connection with content, or how this could be used for educational purposes.

The research questions

This section summarizes the findings throughout the study, by answering the research questions that were drafted in the beginning of this thesis.

1. How to design an on-body projection exhibit that adopts the principles for

effective learning about sustainable development?

In this work, the potential of on-body projections for museums was explored through the design and development of an interactive installation about sustainable fashion. First, a literature review was provided crucial insights on how to implement projection-based techniques for environmental education. This produced a strategy to communicate a positive outlook, and to focus on the emotional aspects of the sustainable exhibit [18, 24, 16, 27, 25]. Moreover, the well-known framework by Csikszentmihalyi was utilized, to enable learning opportunities through intrinsic motivation [36]. This helped to gain insights on what role free-choice learning plays in effective learning in the museum, and how to motivate visitors to learn at exhibits, by offering intellectual, sensory, and emotional stimulation, and an engaging challenge. Additionally, a rationale was gained for utilizing projection-based technologies in museums, for more seamlessly, shared visitor experiences in the real museum environment [4, 5, 6]. Finally, the framework provided an understanding of what to consider when integrating on-body projections, such as the type of content, relationship with the physical object, options for projection-based techniques, and possible interactions.

2. Which design lessons can be drawn when utilizing visitors' bodies as a museum exhibit display?

Then, the guidelines from the framework were adopted while developing the exhibit on sustainable fashion. In the ideation phase, the requirements for the exhibit were investigated through brainstorms with employees, and based on these, three concepts were generated. Finally, the installation was developed and placed in the fashion area. This process produced design lessons for an effective adoption of on-body projections in museum exhibits. Design lessons included on-body projections being at the core of the concept, a mindful placement of the setup for increased usability, considering unsaturated colors and bright lightning for optimal visual effects, using body-tracking for affordable on-body systems, the benefits of a mirror on the visitor experience, and a suggestion to reverse text in the mirror.

3. How do the on-body projections affect visitors' emotional experience with the exhibit content?

Increasing the emotional impact of museum exhibits would be highly beneficial for education on sustainable challenges. Therefore, an investigation was done on the emotional impact of projections onto visitors' bodies in a qualitative evaluation. The studies were compared the installation with on-body projections with projections

onto a conventional enframed surface. The focus group interviews provided an in-depth understanding of visitors' internal thoughts, and emotional perception of the projections. Several themes were identified that played a role in the emotional impact of the on-body projections. First, the visitors enjoyed the the novelty of the on-body technology as an joyful activity by itself. This helped to increase their attention span, and make the experience more memorable. Moreover, the visitors reported that the exhibit content felt more realistically embedded in the museum environment as opposed to the screen display. In turn, the exhibit content seemed to strike them as more personal in the on-body projections, which increased a self-reflective attitude. Finally, visitors perceived higher levels of empathy for the educational message, which is particularly promising for education on awareness-raising issues.

4. To what extent is the on-body exhibit effective in terms of enabling a learning opportunity?

Next, the goal was to investigate the extent that the on-body projection exhibit enabled a learning opportunity for visitors, as well as the influence of the on-body projections separately. This was done through use of the Museum Experience Scale (MES), which measures the learning opportunity of exhibits in terms of internal motivators, through the variables Engagement, Knowledge/Learning, Meaningful Experience and Emotional Connection. This resulted in variable scores of 4.175, 3.859, 4.000, 3.250 on a 5-point Likert scale, with which it is assumed that the learning objectives of the museum exhibit have been met sufficiently. Then, the difference in scores was compared between an experiment with the installation with on-body projections, and the installation with projections onto a conventional surface.

This comparison only showed a significant increase in engagement, whereas the score differences for a emotional connection, or a meaningful experience were non-significant. This being the only outcome was unexpected, as the convincing findings from the interviews indicated higher potential for increasing a meaningful, emotional connection. However, critical issues in the system were identified throughout the study. It is estimated that these could have played a role in the outcome of the scores. Hence, the quantitative study might therefore not fully reflect the potential of on-body projections, and minimizing body-tracking issues in the system is an essential step in future research. Despite these issues, the study provided interesting indications for how on-body projections can be used to engage visitors during their learning process through novel technology.

Contribution to future research

In summary, this work, particularly the focus group interviews, have illustrated the high potential for on-body projections in museum exhibits. Evidence for the contribution of on-body projections on the learning opportunity of exhibits is yet to be found, due to the critical need for body-tracking improvements discovered during this study. Nonetheless, museums are increasingly challenged to embed exhibit content into the environment naturally, and on-body technology offers a novel, seamless, and personal form of display experience, that avoids the use of screens. As visitors can experience a numbing of feelings towards awareness-raising issues displayed on screen-like projections, on-body projections can offer them a way to resonate with the exhibit content on a deeper level. Strong indications are found that on-body projection installations can be beneficial for museums that aim to evoke a stronger connection between their visitors and the exhibit. Therefore, on-body projections seem to be particularly interesting for learning institutions that aim to raise public involvement with particular topics, such as sustainable development. They could provide museums a novel, more personal, and 'real' experience that enables visitors to open up their feelings to the challenges in the world. In this research, the exhibit content mainly consisted of texts displaying sustainable qualities of clothing items. There is still a whole world to explore for on-body projections in museums, in terms of the suitability of other types of content, and other educational topics. This way, museums can keep moving towards making a societal impact on important sustainable challenges.

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Appendix A

Figure 37: Sketch boards with ideas from employees

Table 8: List of ideas and their votes during the brainstorm

Idea	Topic	Votes	
2.	Self-reflection element: How happy do you think the planet is with this piece of clothing?	Enhance curiosity	3
3.	Quiz: different backgrounds that you can stand in front of. Guessing which is the right one.	Immersive game element	3
4.	Choose an item at the clothing racks which you think the fabric is made of	Enhance curiosity	2

5.	Show the original materials throughout the process (e.g. raw wool and the fibers made from it)	Enhance curiosity	1
6.	Add clothing that is made from the literal raw material (or half-half in for example Augmented Reality)	Social interactions	1
7.	What does the material sound like? E.g. (Fishnets: sound of the sea, coffee beans: sound of a coffee machine)	Stimulate the senses	1
8.	Immersive projection onto the person	Stimulate the senses	1
9.	Order a print from a 'webshop' in the fitting room	Stimulate the senses	1
10.	Photos from the people that made the clothing	Immersive game element	1
11.	Cryptic questions about the fabric throughout the fitting process (e.g. this piece grows … per month)	Fascinating information	1
12.	What happens to the clothing when it is finished wearing? (e.g. biodegradable, applicable for compost)	Fascinating information	1
13.	Make a match: Which clothing is made from which material	Enhance curiosity	0
14.	Give some information in the fitting room	Enhance curiosity	0
15.	Look what fabrics I am made of	Enhance curiosity	0
16.	A feel tray: which clothing fits what you feel in the tray	Enhance curiosity	0
17.	A scent jar: which clothing fits what you smell in the jar	Enhance curiosity	0
18.	Banana attire: fabulous attributes to wear next to the clothing pieces	Enhance curiosity	0
19.	Ask the public questions: based on the answers together it becomes clear what the fabric is made of	Enhance curiosity	0
20.	Place the fabric under a magnifying glass: what does it look like?	Social interactions	0
21.	What am I? Bystanders give hints and the person guesses what they are	Social interactions	0
22.	A visual projection that the person on the stage can't see	Social interactions	0
23.	Memory game with the clothing label + a picture of the fabric	Social interactions	0
24.	Competition guessing game + price	Social interactions	0

25.	Fashion show with a photo moment	Social interactions	0
26.	Let bystanders make a text that is projected onto the shirt	Social interactions	0
27.	Place a photo of yourself in the clothing on social media	Social interactions	0
28.	Connect the clothing to something that you can taste	Stimulate the senses	0
29.	Smell the label: part of a guessing game	Stimulate the senses	0
30.	Make the benefits of the fabric more concrete (e.g. show how many fishnets are taken from the sea)	Stimulate the senses	0
31.	Fun facts are tracking the person walking around	Immersive game element	0
32.	Stage + installation is in the style of the fabric materials	Immersive game element	0
33.	A feel book (similar that you can buy for young kids)	Immersive game element	0
34.	Process the materials yourself through crocheting, knitting	Immersive game element	0
35.	Challenge at the clothing racks: pick the most sustainable piece of clothing	Immersive game element	0
36.	Storyline about the making process (e.g. from raw material to fabric)	Fascinating information	0
37.	How long did your piece of clothing take to travel the world?	Fascinating information	0
38.	Guess on a touchscreen (answer a, b, c etc.)	Fascinating information	0
39.	How much material is used for one piece of clothing	Fascinating information	0
40.	Walking out of the fitting room: your footsteps literally the footprint of the clothing	Fascinating information	0
41.	Clothing label contains a curiosity enhancing question	Fascinating information	0

Appendix B

Table 9: IOS scale and questions

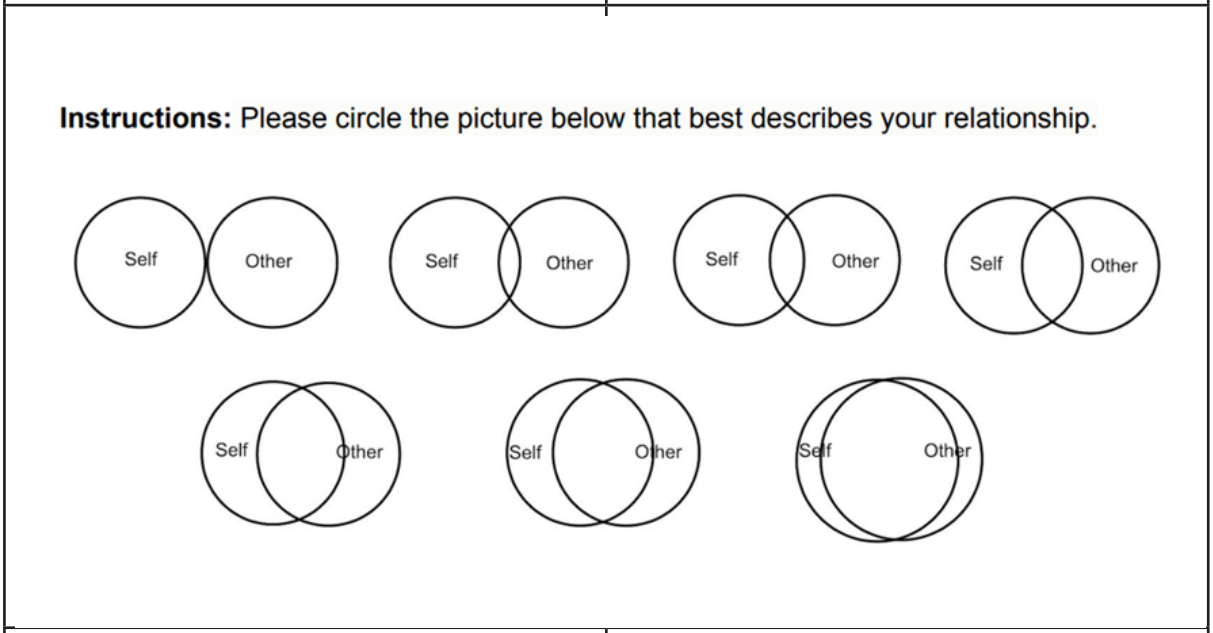
NL	ENG
Wat is je gender?	What is your gender?
Wat is je leeftijd?	What is your age?
Met wie ben je in het museum?	With who did you visit the museum?
Welke van de projecties voelde het meeste onderdeel van het museum? Waarom?	Which of both projections felt most part of the museum environment? Why?
	
Hoe verbonden voelde je je met de virtuele content? Kies één van de opties hierboven. Waarom koos je deze?	How connected did you feel with the virtual content? Pick one of the options above. Why did you choose this one?

Table 10: Focus group interview questions

NL	ENG
Hoe heb je de projecties op jezelf ervaren? En op het scherm? Wat is het grootste verschil?	How did you experience the projections onto yourself? And onto the screen? What is the main difference between them?
Welke keer voelde je je fysiek het meest verbonden met de tekst? En emotioneel? Zat daar verschil tussen?	Which time did you feel most unified with the text physically? And emotionally? Is there a difference?
Hoe identificeerde je je met de tekst? Zat daar verschil tussen bij de projecties op jezelf ten opzichte van de projecties op het scherm?	How did you identify with the text onto yourself? And onto the screen? Was there a difference? How come you think?

Wat als het bijvoorbeeld de boodschap: 'dit shirt is gemaakt van fossiele brandstoffen' was geweest? Hoe ervaar je die tekst dan op jezelf ten opzichte van op het scherm?	What if the message was: 'This shirt is made of fossil fuels'? How would you experience this text onto yourself compared to onto the screen? How come you think?
Denk je dat zulke projecties op jezelf waardevol kunnen zijn voor leren in een museum? Of voor andere doelen?	Would such projections onto yourself be valuable for learning in the museum? Or other purposes?
Hoe zouden projecties op het lichaam leuker gemaakt kunnen worden? Waarom vind je dat?	How can the projections onto the body be made more fun? Why do you think so?

Appendix C

Table 11: IOS scale results and relevant comments

	Tekst op de muur	Tekst op lichaam	Comment
Experiment 1	3	6	
Experiment 2	1	7	"Man: Ja het is wel leuk dat je jezelf zo in de spiegel kan bekijken met het shirt aan en die tekst erop. Dat maakt het wel heel interactief." Vrouw: "Oh ik vind het echt vervelend om het shirt aan te doen. Het is teveel moeite. En bloedheet hier in het museum. En ik wil niet dat hele shirt over mijn hoofd aan moeten trekken".
Experiment 3	2	7	"Het is iets nieuws. En Het is toch meer in het 'hier', met die projecties op je lichaam. Je vergelijkt het ook eerder met jezelf. De boodschap op het scherm lees je van 'Ohja, oke, nou dat dus'. Terwijl het op jezelf meer is van: 'Oh… Ben ik nu… Of draag ik nu bij aan duurzame kleding'. Het komt veel dichterbij. Met een positieve boodschap is dat natuurlijk leuk, maar met een negatieve boodschap mag het liever op het scherm haha. Dan liever cirkeltje 1"
Experiment 4	4	6	Vrouw: "Ik geef het nu een 3, want de tekst moest hoger. Het was niet goed geplaatst, ik hield de hele tijd het shirt omhoog zodat het er goed op stond. Maar als het wel goed geplaatst was op mijn lichaam, dan had ik het wel hoger gegeven, een 5 of 6. (Waarom?) Want het zit dan toch op je eigen lichaam."
Experiment 5	2	6	"Ja het is fysiek dichterbij, maar het voelt ook dichterbij."
Experiment 6	3	7	"Je betrekt het meer op jezelf. Ik ben goed, of ik moet juist meer doen…"
Experiment 7	1	2	
Experiment 8	1	1	"Ik kon het niet goed lezen. In de spiegel was alles omgedraaid. Ja medebezoekers konden het wel goed lezen, bij iemand anders wel. Maar ik voelde me niet verbonden met de tekst als ik niet weet wat er staat."

Experiment 9	3	4	Ik geef het een 1, want ik voelde me net een soort levend standbeeld. Ik kon niet lezen wat er op de tekst stond. Ik had het een 4 gegeven als ik het wel had kunnen lezen.”
Experimentt 10	1	1	“Ik merkte niet echt een link met mezelf, en ik voelde ook geen verschil tussen de verschillende experimenten. Misschien heb ik de boodschap gemist, maar dat merkte ik niet nee”.

Table 12: Focus group interview 1

Visitor group composition	Family	Open codes
Visitor group size	2	
Participant age	6-10, 41-50	
How did you experience both forms of projections? What is the main difference between them? How come you think?	Kind: “Die op het scherm was leuk. Die andere ook.” Vrouw: “het is gek omdat het ook op je lijf zit. Het is wat anders dan normaal.”	Different than usual
With which form of projections did you feel most unified physically? And emotionally? Is there a difference? How come you think?	Kind: “Leuker op mijn buik.”	
Researcher: “En waarom vond je dat denk je?” “Weet ik niet haha. Gewoon.”	Preference: on-body 1x	
How did you experience seeing the projections onto yourself? And onto someone else? Is there a difference? How come you think?	Vrouw: “Ik heb vooral geluisterd naar de stem.”	
How did you identify with the sustainable message onto yourself? And onto the wall? Was there a difference? How come you think?	Vrouw: “Deze vraag is meer voor volwassen denk ik, ik weet niet of kinderen dit al begrijpen. Maar je gaat je wel anders inleven”.	Empathize differently
What do you think of museum content being projected onto yourself compared to projections onto a screen? Is there a difference? How come you think?	Vrouw: “Dit doet me denken aan een installatie in een ander museum, die vonden we wel heel leuk. Toch?”	

Kind knikt instemmend. "Dat was in Boerhaven. Daar kon je je botten zien, en enzymen op je lichaam. Je lijf werd gescand en dan had je opeens een wondje en dan moest je een pleister op de wond plakken. Die was technisch wel wat beter.	Technical improvements required	
What if the message was: 'This shirt is made of fossil fuels'? How would you experience this message onto yourself compared to onto the screen? How come you think?	Vrouw: "Kijk, een voorbeeld. Die trui is gemaakt in een fabriek. Als dat op je trui stond had je dat dan vervelend gevonden?" Kind: "Uhm…" Vrouw: "Als er gif vrijkomt omdat die trui is gemaakt, vind je dat dan erg?" Kind: "Een beetje." Vrouw: "En vind je dat dan erger om te lezen op je lijf dan op het scherm?" Kind: "Dan lees ik het liever op het scherm".	Negative messaging preferred on-screen
What else could we use such projections onto yourself for? Would it be valuable for other purposes? How come you think?	Vrouw: "Ik vind dit soort dingen leuk, het is net wat anders, nieuwig ofzo. Je kan hiermee bezoekers geprikkeld raken om nieuwe dingen te ontdekken." Kind knikt instemmend.	New way of learning. Stimulating discovering new things
How can the projections onto yourself be made more fun? Why do you think so?	Vrouw: "Ik vond het geluid te zacht. En het zou leuk zijn om wat meer te leren over die materialen. Wat kan je nog meer met bamboo, naast kleding maken, bijvoorbeeld. En er moeten wat duidelijkere bordjes en aanwijzingen komen."	More learning content. Better instructions

Table 13: Focus group interview 2

Visitor group composition	Familie	Open codes
Visitor group size	3	
Participant age	11-20, 41-50, 41-50	

How did you experience both forms of projections? What is the main difference between them? How come you think?	Man: "Ik had in de spiegel helemaal niet de achtergrond van petflessen gezien, want de tekst was achterstevoren. Daardoor was ik veel meer bezig met ontcijferen wat er nou precies stond." Kind: "De tekst moet misschien andersom". Man: "Ja dat zou wel helpen". Vrouw: "Het gepraat is heel langzaam. En ik sta hier wel vaker en dan heb ik het idee dat hij niet altijd werkt. Kinderen slaan erop, maar dan gebeurt er niks. En hij loopt hoe dan ook wel door, of je nou iets doet of niet".	Difficulty reading due to reverted text Interaction not working
With which form of projections did you feel most unified physically? And emotionally? Is there a difference? How come you think?	Man: "Ja, je bent gewend om naar een scherm te kijken. Misschien een beetje een extreem voorbeeld, maar de oorlog in oekraine, dat is zo anders als je het ziet in het echt, dan op TV. Je ziet de hele dag door van alles op een TV of een scherm. Een vrouw die in Oekraine was zei dat het zoveel heftiger in het echt is. Ik denk dat dat hiermee ook een beetje zo is. Als je zo'n boodschap op jezelf ziet, dan wordt het bij jezelf betrokken en wordt het veel persoonlijker."	Message becomes more real. More personally involved. Excessive use of screens
How did you experience seeing the projections onto yourself? And onto someone else? Is there a difference? How come you think?	Kind: "Het is denk ik wel leuker op jezelf".	Preference: on-body 1x

How did you identify with the sustainable message onto yourself? And onto the wall? Was there a difference? How come you think?	Man: "Als je zo'n boodschap op jezelf ziet, wordt het veel persoonlijker'.	Message becomes more personal
What do you think of museum content being projected onto yourself compared to projections onto a screen? Is there a difference? How come you think?	Man: "Ja, ik vind dat hier wel potentie in zit." Vrouw: "Ja ik vind het idee wel leuk, maar dan moet hij wel wat beter werken".	Preference: on-body 2x. Technical improvements required
What if the message was: 'This shirt is made of fossil fuels'? How would you experience this message onto yourself compared to onto the screen? How come you think?	Man: "Liever met een positieve boodschap, dan vanuit een soort angst opwekken. Dat zien mensen toch alleen maar als gezeur. Iets positiefs kan juist meer tot beweging aanzetten".	Negative messages preferred on-screen
What else could we use such projections onto yourself for? Would it be valuable for other purposes? How come you think?	Man: "Misschien boven bij de tentoonstelling over Romeinen. Dat je een Romeins pak kan aantrekken om te kijken hoe het staat. Dat zou wel heel erg leuk zijn."	
How can the projections onto yourself be made more fun? Why do you think so?	Man: "Deze installatie was niet heel interactief. Zou leuk zijn als het wat interactiever is. De tekst ook spiegelen zodat je het duidelijker in de spiegel kan lezen. Dan zou ik het cirkeltje ook een 7 hebben gegeven, als je het meteen snapt. Dat maakt de boodschap een stuk persoonlijker. Nu heb ik het een 4 gegeven."	Higher emotional connection if text reversed

Table 14: Focus group interview 3

Visitor group composition	Family & friend group	Open codes
Visitor group size	2	
Participant age	6-10, 31-40	

How did you experience both forms of projections? What is the main difference between them? How come you think?	Kind: "ik vond het allebei leuk".	Preference: both 1x
With which form of projections did you feel most unified physically? And emotionally? Is there a difference? How come you think?	Kind: "Weet ik niet".	
How did you experience seeing the projections onto yourself? And onto someone else? Is there a difference? How come you think?	Kind: "Ik begrijp het niet precies".	
How did you identify with the sustainable message onto yourself? And onto the wall? Was there a difference? How come you think?	Kind: "Ik begrijp het niet echt…".	
What do you think of museum content being projected onto yourself compared to projections onto a screen? Is there a difference? How come you think?	Kind: "Iets slechts op jezelf zou niet leuk zijn. Dan is het alsof je zelf slecht bent. Dan heb ik het liever op het scherm haha."	Negative messages preferred on-screen. Sense of personal association
What if the message was: 'This shirt is made of fossil fuels'? How would you experience this message onto yourself compared to onto the screen? How come you think?	Kind: "Ja het is wel leuk om zoiets nieuws te proberen".	New way to learn things
What else could we use such projections onto yourself for? Would it be valuable for other purposes? How come you think?	Kind: "Dat weet ik niet haha." Vrouw: "Waar zou dit nog meer leuk voor zijn? Misschien een filmpje op jezelf?" Kind: "Ja dat zou ook leuk zijn!"	
How can the projections onto yourself be made more fun? Why do you think so?	Kind: "Nee het was helemaal goed zo, niks meer aan veranderen."	

Table 15: Focus group interview 4

Visitor group composition	Family	Open codes
Visitor group size	1	
Participant age	38	
How did you experience both forms of projections? What is the main difference between them? How come you think?	Vrouw: "Ik vond de leesbaarheid het grootste verschil. Bij die op het scherm kon ik het wel lezen en op die andere wat moeilijker."	
With which form of projections did you feel most unified physically? And emotionally? Is there a difference? How come you think?	Vrouw: "Ja er zou wel een verschil zijn als je het zelf zou kunnen lezen. Maar nu was de tekst in spiegelbeeld. Dan herken ik het niet".	Difficulty reading due to reversed text
How did you experience seeing the projections onto yourself? And onto someone else? Is there a difference? How come you think?	Vrouw: "Ja het is wel een raar gevoel. Het zou raarder zijn op jezelf, want het is toch op je lichaam. Zelfs al is het in spiegelbeeld, het doet wel wat"	Different, weird sensation
How did you identify with the sustainable message onto yourself? And onto the wall? Was there a difference? How come you think?	Vrouw: "Ja zoiets helpt wel met zaken rondom bewustwording denk ik."	Effective for awareness issues
What do you think of museum content being projected onto yourself compared to projections onto a screen? Is there a difference? How come you think?	Vrouw: "Ja het is op je lichaam, dus dan zou het wel meer impact hebben".	More emotional impact on-body
What if the message was: 'This shirt is made of fossil fuels'? How would you experience this message onto yourself compared to onto the screen? How come you think?	Vrouw: "Dat zou meer negatieve impact hebben. Dan liever op een scherm."	Negative messaging preferred on-screen

What else could we use such projections onto yourself for? Would it be valuable for other purposes? How come you think?	Vrouw: "Ik zit even te denken. Het zou kunnen bij naar school gaande kinderen. De gevoelens van andere kinderen. Dat je dan iets meer voelt hoe iemand anders zich voelt. Dat zou wel kunnen helpen denk ik met bewustwording van hoe anderen zich voelen."	Suggestion: feelings of bullied children
How can the projections onto yourself be made more fun? Why do you think so?	Vrouw: "Allereerst het spiegelen van de tekst. Misschien wat verstelbaar qua hoogte. Bij een kind staat het op je hoofd. En een aparte instelling voor kinderen en volwassenen zou handig zijn want het stond niet op mij, ik moest het shirt verschuiven om de tekst op de juiste plek te krijgen".	Misplacement of texts

Table 16: Focus group interview 5

Visitor group composition	Family	Open codes
Visitor group size	2	
Participant age	6-10	
How did you experience both forms of projections? What is the main difference between them? How come you think?	Kind: "Op jezelf had ik het wel leuker dan op het scherm. Maar je moet wel een beetje stilstaan anders kan je het niet zien." Vrouw: "Dit is een keer niet op het bord maar op iemand. Daarmee let je wat meer op. Op het bord zie je heel vaak. Dit is anders dan anders."	Preference: on-body 2x. Misplacement of tekst due to body tracking. Higher attention span. New way to learn Excessive use of screens
With which form of projections did you feel most unified physically? And emotionally? Is there a difference? How come you think?	Vrouw: "Dit vergeet je minder snel. Je wordt er beter bij betrokken, en je moet ook meer opletten".	Longer memory retention

How did you experience seeing the projections onto yourself? And onto someone else? Is there a difference? How come you think?	Kind: "Op de rug, want ik kijk al heel vaak op een schermpje. Dat is ook niet goed voor je de hele tijd. Dan is dit ook beter voor je ogen."	Excessive use of screens
How did you identify with the sustainable message onto yourself? And onto the wall? Was there a difference? How come you think?	Kind: "Ik zou het vaker willen gebruiken op jezelf. Dan ben je extra betrokken."	Higher sense of involvement
What do you think of museum content being projected onto yourself compared to projections onto a screen? Is there a difference? How come you think?	Kind: "Liever op jezelf. Dan kan je denken dat jij iets goeds hebt gedaan."	Higher sense of self-association
What if the message was: 'This shirt is made of fossil fuels'? How would you experience this message onto yourself compared to onto the screen? How come you think?	Moeder: "Ik vind dit leuk zo, andere vormen bedenken om te leren. We zullen de PET flessen niet snel vergeten. Op deze manier beklijft het meer."	
What else could we use such projections onto yourself for? Would it be valuable for other purposes? How come you think?	Moeder: "Infofilmpjes voor op jezelf. Informatie van spullen. Op deze manier wordt de essentie er beter uitgehaald. Het blijf een beetje afwisselend. Ik ben zelf lerares op school, en daar zou ik het ook wel willen gebruiken, om onderwerpen op een andere manier aan te bieden. Sommige kinderen zijn heel visueel ingesteld, dan kan dit echt helpen."	
	Suggestion: use in classrooms for visually oriented children	

How can the projections onto yourself be made more fun? Why do you think so?	Kind: "Andere plaatjes. Afwisseling. Bijvoorbeeld leuke plaatjes van een poes of dieren. Heelal ander thema ander plaatje.	

Table 17: Focus group interview 6

Visitor group composition	Family	Open codes
Visitor group size	2	
Participant age	11	
How did you experience both forms of projections? What is the main difference between them? How come you think?	Kind: "Ik vond het wel cool, waar komt de tekst nou. Vond ik eigenlijk wel leuk. Maar het was jammer dat ik het niet heel goed kon lezen, in de spiegel kon je het wel lezen, maar al ik naar beneden keek niet."	Reading difficulty due to reverted text
With which form of projections did you feel most unified physically? And emotionally? Is there a difference? How come you think?	Kind: "Het voelde meer alsof jij het was." Vrouw: "Ja dat denk ik ook wel".	Higher sense of personal association 2x
How did you experience seeing the projections onto yourself? And onto someone else? Is there a difference? How come you think?	Vrouw: "Ik vond het leuker op jezelf. Eerst ook echt op jezelf kijken door rechtdoor in de Spiegel te kijken. Ik denk ook dat je daardoor wat beter luistert naar de stem. Dit maakt het uitdagender, je moet beter opletten."	Preference: on-body 1x. More challenging. Higher attention required
How did you identify with the sustainable message onto yourself? And onto the wall? Was there a difference? How come you think?	Kind: "Ja meer dat je denkt dat het over jou gaat. Dat ben jij als de projecties op je lichaam staan."	
What do you think of museum content being projected onto yourself compared to projections onto a screen? Is there a difference? How come you think?	Kind: "Leuk voor koffiebonen had ik niet geraden. Ik heb liever allebei. Bij de ene moet je meer concentreren op wat de stem zegt. En je kijkt meer om je heen".	Preference: both 1x

What if the message was: 'This shirt is made of fossil fuels'? How would you experience this message onto yourself compared to onto the screen? How come you think?	Kind: "Slecht voor het milieu. Ik wil best wel goed zijn, rijdt heel veel met de fiets. Dat mijn kleren goed zijn vind ik belangrijk. Dus bij een slechte tekst heb ik het liever op het scherm, dan staat het niet zo op mij. Dan heb je het gevoel dat jij slecht bent."	On-screen preferred for bad messages
What else could we use such projections onto yourself for? Would it be valuable for other purposes? How come you think?	Kind: "Ja. Maar soms wist je door de achtergrond al meteen wat het is." Vrouw: "Met de schapen wisten we meteen al wat het is toen de installatie begon. Dus zoiets maar dan dat je niet meteen weet wat het is."	Too easy to guess
How can the projections onto yourself be made more fun? Why do you think so?	Kind: "Meer in het Duits!" Vrouw: "Wij komen uit Duitsland en spreken geen Nederlands. Er zijn heel veel Duitse mensen hier."	

Table 18: Focus group interview 7

Visitor group composition	Family & friend group	Open codes
Visitor group size	2	
Participant age	6-10, 31-40, 31-40	
How did you experience both forms of projections? What is the main difference between them? How come you think?	Vrouw: "Het blijft nog steeds wel een extern iets, maar de tekst op jezelf heeft meer impact. Het voelt meer als onderdeel van mij, maar nog steeds gaat het over een stukje kleding. Het gaat uiteindelijk over een keuze die ik maak, maar is geen onderdeel van mij."	Higher sense of unity, but still separate entity

With which form of projections did you feel most unified physically? And emotionally? Is there a difference? How come you think?	Vrouw: "Het vraagt meer je aandacht. Anders is het snel een scherm 1 van de 300000 andere schermen. Dan vraagt het je aandacht, ohja dit draag ik en gaat ook over mij."	More attention Excessive use of screens
How did you experience seeing the projections onto yourself? And onto someone else? Is there a difference? How come you think?	Vrouw: "Het is meer een confrontatie met de keuze die je dan maakt. Dus positief, laat je uberhaupt over nadenken wat je koopt. Maar het is niet altijd de juiste keuze die je maakt."	More confrontational. Higher sense of self-reflection
How did you identify with the sustainable message onto yourself? And onto the wall? Was there a difference? How come you think?	Man: "Zet aan tot denken. Veel mindere mate met zo'n scherm, want schermen zie ik de hele dag al. Ik ben getraind om niet echt meer op te letten."	Higher sense of self-reflection. Excessive use of screens
What do you think of museum content being projected onto yourself compared to projections onto a screen? Is there a difference? How come you think?	Man: "Ik zou wel kiezen voor een positieve confrontatie, anders dan gaan mensen het uit de weg. Dan vinden ze het niet leuk."	
What if the message was: 'This shirt is made of fossil fuels'? How would you experience this message onto yourself compared to onto the screen? How come you think?	Vrouw: "Bij wol in de installatie bijvoorbeeld denk ik, dat laat je slechter voelen, want dat is niet altijd goed. Op het scherm staat het verder van je af. Over jezelf heen ligt meer gaat het meer over mij."	Higher sense of personal association

What else could we use such projections onto yourself for? Would it be valuable for other purposes? How come you think?	Vrouw: "We zijn net binnen, dus dat is lastig te beoordelen. Maar het laat je wel stilstaan, wat één van de doelen van het museum is. Maar het kan ook voor commerciële doeleinden, omdat het je aandacht vraagt en betrekking heeft op jezelf. Of bijvoorbeeld dingen als aandacht vragen voor baarmoederhalskanker. Dingen als confrontaties, bewustwording, daar zou het wel bij werken."	More confrontational. Effective for awareness issues. Suggestion: Asking attention for cervical cancer
How can the projections onto yourself be made more fun? Why do you think so?	Vrouw: "Er was hier heel veel afleiding. Het zou meer impact hebben als je bijvoorbeeld even in een box zit met alleen jij." Man: "Hier is overal geluid, kleuren, licht, andere mensen, dat is veel afleiding."	Personal intimite experience

Table 19: Focus group interview 8

Visitor group composition	Family	Open codes
Visitor group size	2	
Participant age	12, boy with mother	
How did you experience both forms of projections? What is the main difference between them? How come you think?	Kind: "Liever op het scherm." Vrouw: "Op de jas kan er iets voor zitten of kreukelt het. Dat stoort."	Preference: on-screen 1x. Reading difficulty due to wrinkled clothes
With which form of projections did you feel most unified physically? And emotionally? Is there a difference? How come you think?	Vrouw: "Als je het aan hebt kan ik het misschien beter aanvoelen. Als je het past vind ik het een leukere ervaring. Dat wordt actiever, dan alleen informatie aflezen van een scherm. Nu pak je m houd je het voor je, daardoor kan je er beter mee connecten. Alsof je het beter kan passen, alsof je het voor je houdt."	Preference: on-body 1x

How did you experience seeing the projections onto yourself? And onto someone else? Is there a difference? How come you think?		
How did you identify with the sustainable message onto yourself? And onto the wall? Was there a difference? How come you think?		
What do you think of museum content being projected onto yourself compared to projections onto a screen? Is there a difference? How come you think?	Vrouw: "Maakt niet zoveel uit, maar ik zou het niet sneller kopen. Omdat het ook goed moet voelen."	
What if the message was: 'This shirt is made of fossil fuels'? How would you experience this message onto yourself compared to onto the screen? How come you think?	Kind: "Liever op het scherm." Moeder: "Is dat wel echt zo? Welk museum vind jij leuker? Waar je alleen kijken kan en lezen, of ook onderzoeken? Wat vind je dan leuk? Wil je iets doen? Een opdracht ofzo, of wil je kijken?" Kind: "Ja dan wil ik liever iets doen." Moeder: "En iets nieuws ontdekken." Kind: "Ja. Maar dat was nu minder want ik kon het minder goed lezen, dus dat maakte het minder leuk."	New way of learning
What else could we use such projections onto yourself for? Would it be valuable for other purposes? How come you think?	Vrouw: "Misschien een quiz, zoals een soort natuurquiz, en dan krijg je de antwoorden over je heen. Bijvoorbeeld dat je verschillende dierenvachten hier zou ophangen, en dan aan bezoekers vragen wat voor dier het is."	

How can the projections onto yourself be made more fun? Why do you think so?	Vrouw: "Het moet leesbaar, maar het is wel goed geschreven. Het zijn leuke dingen om te leren. Zo ontdek je heel veel over de natuur. Of probeer iets met Virtual Reality. Dat vind mijn zoon heel leuk, dan kun je dingen besturen. Kind: "Ja dat heb ik wel een keer eerder in een museum gehad, met de bril op. Dat was leuk."	Readability issues

Table 20: Focus group interview 9

Visitor group composition	Family	Open codes
Visitor group size	3	
Participant age	women, man, child (14)	
How did you experience both forms of projections? What is the main difference between them? How come you think?	Vrouw: "Ik voelde me een levende tentoonstelling bij de tekst op mezelf, want ik kon het niet lezen dus ik had er niks aan." Man: "Wij konden het wel lezen hoor! Voor ons was het prima." Vrouw: "Ja voor jullie wel."	Readability issues due to reverted text

With which form of projections did you feel most unified physically? And emotionally? Is there a difference? How come you think?	Man: "Ja ik had zelf geen connectie met de tekst toen jij er stond, maar dat was omdat jij het was. Tussen jou en de tekst was de relevantie wel groter ja. Het hoorde opeens bij jou. Jongen: "Ja dat vond ik ook". Vrouw: Die op het lichaam vond ik toch wel beter." Man: "Ik ook". Kind: "Ja." Vrouw: "Ik had zoiets van: wat gebeurt er nou? Ineens zit het op mijn lijf, alsof je iets aantrekt, alsof je een tekst aantrekt. Nee dat is wel leuker, als ik het kon lezen tenminste." Man: "Je moet het omwisselen. Om de zoveel tijd dat je de tekst verwisselt. Dan kunnen zowel bezoekers als degene die het doet het lezen."	Higher sense of relevance. Preference: on-body 3x. Different sensation
How did you experience seeing the projections onto yourself? And onto someone else? Is there a difference? How come you think?	Vrouw: "Jawel, positieve keuze te maken. In al die economische zooi, wat kan je nou toch doen? Dat is allemaal nogal negatief. Nou weet je dat je dit ook kan dragen. Kunnen we onze koffie toch nog ergens voor gebruiken.:	
How did you identify with the sustainable message onto yourself? And onto the wall? Was there a difference? How come you think?	Moeder: "Leuk, grappig. Nouja je zag het. We deden het allemaal. Om dit zo te doen, zelf te kiezen. Actief te zijn."	
What do you think of museum content being projected onto yourself compared to projections onto a screen? Is there a difference? How come you think?	Vrouw: "Voor kleding vind ik het erg logisch." Man: "Ik kan zo even niks anders verzinnen."	

What if the message was: 'This shirt is made of fossil fuels'? How would you experience this message onto yourself compared to onto the screen? How come you think?	Vrouw: "Het positief brengen is leerzamer. En dan liever graag lezen op jezelf, dan raakt het meer, dat is logisch." Man: "Nou dat komt dan wel harder binnen denk ik." Vrouw: "Nee joh het helpt niks, je krijgt op je kop voor niks in dat geval. Wat kun je dan doen?"	More confrontational
What else could we use such projections onto yourself for? Would it be valuable for other purposes? How come you think?	Vrouw: "Nouja je zou het misschien op een schilderij kunnen projecteren. Voor extra informatie ofzo".	
How can the projections onto yourself be made more fun? Why do you think so?	Vrouw: je moet het kunnen lezen in de spiegel. Omdraaien	Suggestion: reverted text

Table 21: Focus group interview 10

Visitor group composition	Family	Open codes
Visitor group size	2	
Participant age	11-20	
How did you experience both forms of projections? What is the main difference between them? How come you think?	Kind: "Het scherm was makkelijker. Best moeilijk om het shirt te lezen, en in spiegelbeeld was het al helemaal lastig." Vrouw: "Eigenlijk moeten ze het omdraaien. Dan zou het wel grappig zijn, alsof je echt voor de mode voor de spiegel staat."	Preference: on-body 1x IF more readable
With which form of projections did you feel most unified physically? And emotionally? Is there a difference? How come you think?	Kind: "Niet echt een verschil." Vrouw: "Ik voelde geen extra betrokkenheid." Kind: "Op jezelf was wel anders in spiegelbeeld dan op een ander. Niet per sé leuker of minder leuk"	No different sense of involvement 2x

How did you experience seeing the projections onto yourself? And onto someone else? Is there a difference? How come you think?	Vrouw: "Ik zou me er niet mee identificeren, dus dit ben ik dan ook."	No sense of personal association
How did you identify with the sustainable message onto yourself? And onto the wall? Was there a difference? How come you think?	Vrouw: "Vond je het een leuke manier?" Kind: "Het scannen was leuk, een soort quizje want je wist nog niet wat het was dat was ook leuk. Het was grappig dat het op het shirt kwam." Vrouw: "Ik zou het liever bij het scannen op het shirt laten. Dat is een beetje anders dan anders." Kind: "Ik vond het op het shirt wel leuk. Maar dan moet je het wel kunnen lezen".	
What do you think of museum content being projected onto yourself compared to projections onto a screen? Is there a difference? How come you think?		
What if the message was: 'This shirt is made of fossil fuels'? How would you experience this message onto yourself compared to onto the screen? How come you think?	Vrouw: "Dit kan voor heel veel dingen, waar je iets over wil vertellen. Dan moet je het scannen en dan info krijgen."	
What else could we use such projections onto yourself for? Would it be valuable for other purposes? How come you think?	Vrouw: "Dat het in de spiegel ook bekeken kan worden is goed, anders blijf je rondkijken van wat is de bedoeling nou? Voor de mode is een spiegel ook beter dan een scherm, het past beter bij het thema".	Mirror an essential addition
How can the projections onto yourself be made more fun? Why do you think so?	Kind: "Beter lezen".	

Study – Additional notes 1st round	Open codes
Man: (41-50): 'Ik heb betere antwoorden ingevuld voor de laatste, maar ik vond de eerste beter. Ik moest er alleen eerst even achter komen hoe het werkte enzo. Nadat ik dat had ontdekt vond ik de tekst op je buik erg cool. Maar het moet nog wel wat gefine-tuned. De spiegel staat te ver weg, daardoor werd mij niet meteen duidelijk waar ik moest kijken. Maar het idee is heel cool. Heel interactief en wat anders dan anders. Ook leuk dat andere mensen kunnen meekijken. Maar dan moet er dus nog wel wat verbeterd worden. De spiegel is wel essentieel.	Mirror is essential Mirror too far
Vrouw (21-30): Ik zie nu dat er een spiegel bij is. Dan is die met projecties op het lichaam echt leuker. Het is alsof je de tekst ook echt aan hebt ook.	Mirror essential
Vrouw (31-40): Ik vond die op het lichaam leuker dan die andere (scherm). Dat kwam omdat de spiegel niet breed genoeg was. Ik kon de vraagtekens er helemaal niet op zien dus ik wist steeds niet waar ze waren. Dat maakte het wel verwarrend.	Mirror too narrow
Vrouw (31-40): Ik vond die met de tekst over me heen wel echt leuker. Ja want dan wordt je er wat meer bij betrokken. Leuk vooral met die spiegel, die combinatie doet 't 'm. Want dan kun je jezelf ook zien met die tekst over je heen, dat is een leuk effect. Ik heb hier wel eerder zonder spiegel gestaan en dan dacht ik, wat is de bedoeling nou?	Mirror essential
Man (11-20): Het scherm was leuker want die vond ik duidelijker. Daar kon ik me beter focussen. Bij die andere, al helemaal zonder spiegel, ben je vooral bezig met ontcijferen wat er nu precies gebeurd. Ik vind de spiegel wel een goeie toevoeging trouwens. Dan kun je wel wat meer zien.	Mirror essential

Appendix D

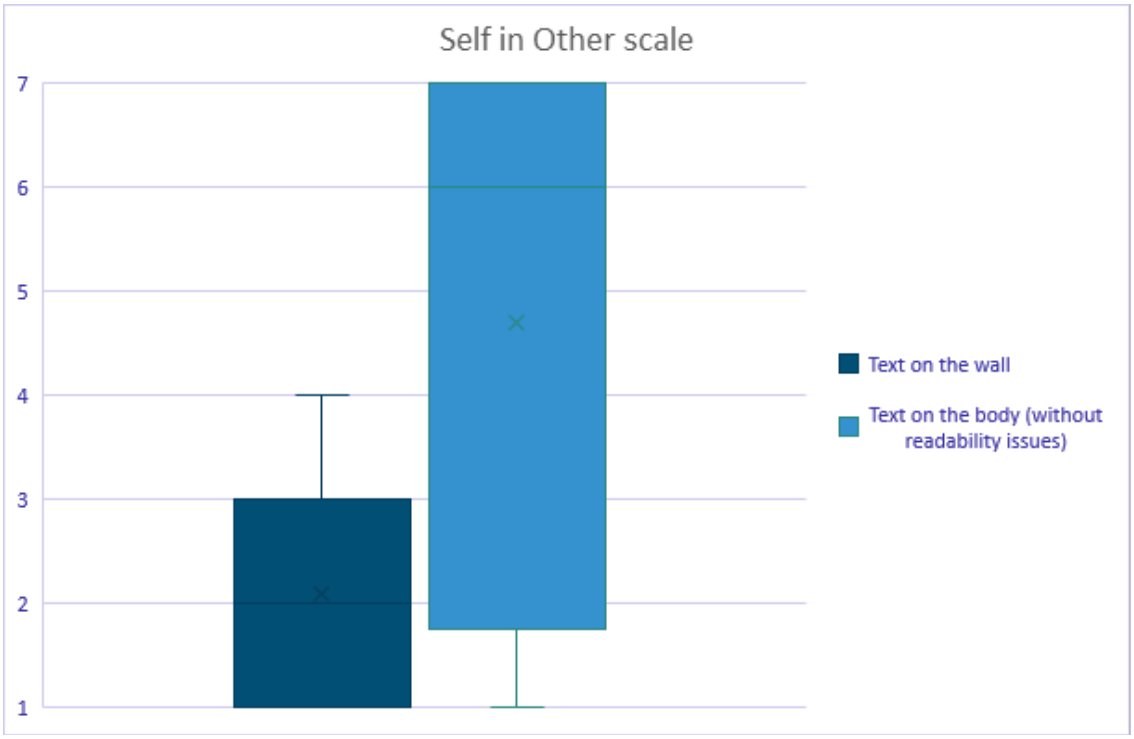


Figure 38: Boxplot IOS on-screen versus on-body without readability issues

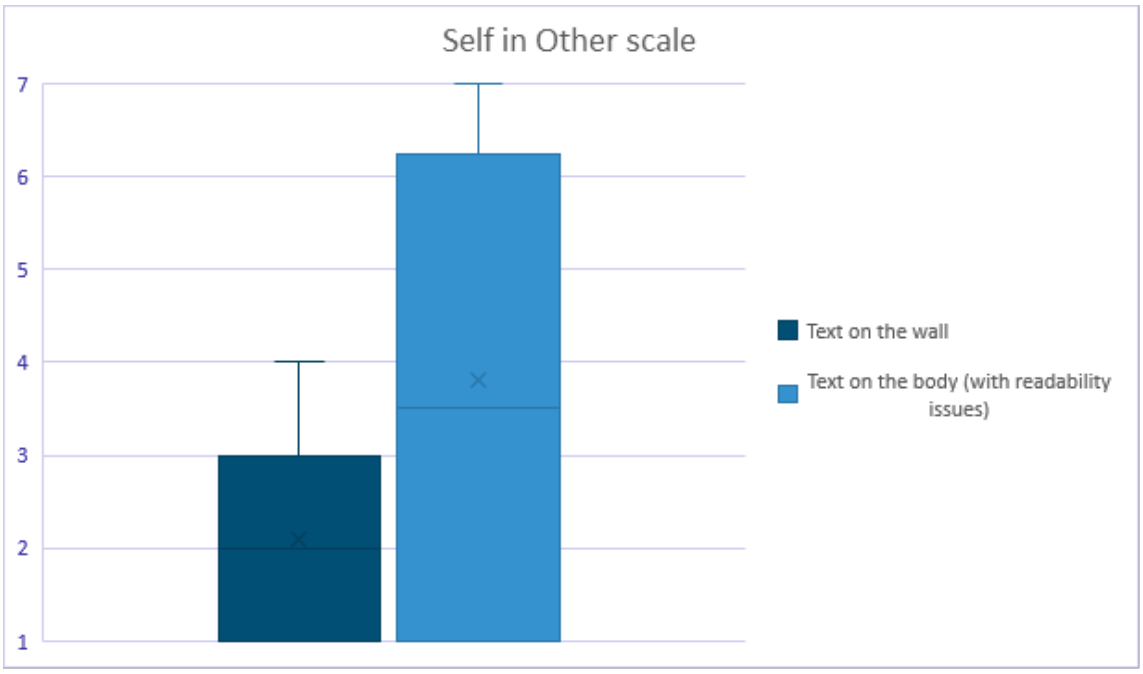


Figure 39: Boxplot IOS on-screen versus on-body with readability issues

Appendix E

Table 22: MES questionnaire original

Engagement	Knowledge/Learning
I enjoyed visiting the exhibition	The information provided about the exhibits was clear
I felt engaged with the exhibition	I could make sense of most of the things and saw and did at the exhibition
My visit to the exhibition was very interesting	I liked graphics associated with the exhibition
I felt like I was experiencing the exhibition, rather than just visiting it	My visit enriched my knowledge and understanding about specific exhibits
My visit to the exhibition was inspiring	I discovered new information from the exhibits
Meaningful Experience	Emotional Connection
During my visit I was able to reflect on the significance of the exhibits and their meaning	The exhibition enabled me to reminisce about my past
During my visit, I put a lor of effort into thinking about the exhibition	My sense of being in the exhibition was stronger than my sense of being in the real world (reversed relationship)
Seeing rare exhibits gave me a sense of wonder about the exhibition	I was overwhelmed with the aesthetic/ beauty aspect of the exhibits
After visiting the exhibition, I was still interested to know more about the topic of the exhibition	I wanted to own exhibits like those I saw I the exhibition
Seeing real exhibits of importance was most satisfying aspect of my visit to the exhibition	I felt connected with the exhibits

MES scale statements English adapted

Adaptations mostly involved changing the word ‘exhibition’ to ‘exhibit’, changing plural to single words, and fixing minor typing mistakes.

Table 23: MES scale questionnaire adapted

Engagement	Knowledge/Learning
I enjoyed visiting the exhibit	The information provided about the exhibit was clear
I felt engaged with the exhibit	I could make sense of most of the things I saw and did at the exhibit
My visit to the exhibit was very interesting	I liked graphics associated with the exhibit

I felt like I was experiencing the exhibit, rather than just visiting it	My visit enriched my knowledge and understanding about specific exhibit
My visit to the exhibit was inspiring	I discovered new information from the exhibit
Meaningful Experience	Emotional Connection
During my visit I was able to reflect on the significance of the exhibit and its meaning	The exhibit enabled me to reminisce about my past
During my visit, I put a lor of effort into thinking about the exhibit	My sense of being in the exhibit was stronger than my sense of being in the real world (reversed relationship)
	I was overwhelmed with the aesthetic/ beauty aspect of the exhibit
After visiting the exhibit, I was still interested to know more about the topic of the exhibit	I wanted to own the exhibit that I just saw
Seeing real exhibits of importance was most satisfying aspect of my visit to the exhibit	I felt connected with the exhibit

MES scale statements translated to Dutch

As there is not a sufficient word for a single exhibit in the Dutch language, the wording for 'tentoonstelling' might confuse visitors to evaluate on the whole exhibition. To avoid confusion, the visitors were told that this study explicitly focuses on the system they just experienced in the fashion area.

Table 24: MES scale questionnaire Dutch

Engagement	Knowledge/Learning
Ik heb genoten van het bezoek aan de tentoonstelling	De informatie over de tentoontstelling was duidelijk.
Ik voelde me betrokken bij de tentoonstelling	Ik kon de meeste dingen begrijpen die ik zag en deed bij de tentoonstelling.
Mijn bezoek aan de tentoonstelling was erg interessant	Ik vond de beelden die bij de tentoonstelling horen leuk.
Ik had het gevoel dat ik de tentoonstelling aan het ervaren was, in plaats van hem alleen te bezoeken	De tentoonstelling heeft mijn kennis en begrip over een specifiek thema verrijkt.
Mijn bezoek aan de tentoonstelling was inspirerend	Ik ontdekte nieuwe informatie in de tentoonstelling.
Meaningful Experience	Emotional Connection
Tijdens mijn bezoek kon ik nadenken over de relevantie van de tentoonstelling en de betekenis.	Door de tentoonstelling kon ik herinneringen ophalen aan mijn verleden.

Tijdens mijn bezoek heb ik veel energie gestoken in het nadenken over de tentoonstelling.	Mijn gevoel in de tentoonstelling te zijn was sterker dan mijn gevoel in de echte wereld te zijn (omgekeerde relatie)
Na het bezoek aan de tentoonstelling was ik nog steeds geïnteresseerd om meer te weten over het onderwerp van de tentoonstelling.	Ik was overweldigd door het estethische/schoonheidsaspect van de tentoonstelling
Het zien van een echt en relevant thema was het meest bevredigende aspect van de tentoonstelling.	Ik wilde de tentoonstelling bezitten
	Ik voelde me verbonden met de tentoonstelling

Appendix F

Requirements for the T-test

1. Normality check:

1. Skewness. Statistic / Std. Error. Should be between -1.96 and 1.96 for normality assumption.
   All variables can be considered normally skewed.
2. Kurtosis. Between -1.96 and 1.96.
   All variables are between the required values. Normal distribution can be assumed.
3. Test of Normality table. Less than 100 entries -> Look at Shapiro-Wilk. Significance should be > 0.05. Then normal distribution can be assumed.
   All values are > 0.05. Therefore, normal distribution is not rejected.

2. Assumptions Paired samples T-Test

1. Appropriate measurement scale
   The Paired T-Test can be conducted on interval or ratio data. As the Likert items are combined into overall variables, the data can be treated as interval. This is an appropriate measurement scale for this type of statistical test.
2. Independency of variables
   All experiments were conducted independently of the other experiments. Therefore, the samples are assumed to be independent.
3. Reasonably large sample size
   During the experiments a total of 16 participants have been recruited. For a statistical test, this number is on the lower side. It is decided to run the tests, but this limitation should be kept in mind when interpreting the results.