Exploring the Tangibility of Intelligent Agents through Shape-change in the Context of Shopping Clothes Online

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Figure 1. Three tangible intelligent agents for shopping clothes online.

ABSTRACT
Shape-changing interfaces are tangible user interfaces that connect the digital and physical worlds. This is an interesting area for Artificial Intelligence (AI), where making it physical can improve the user's understandability and transparency of the intelligent system. A digital context where AI is used and tangibility is often missed is shopping for clothes online. Several tangible prototypes were created through co-design sessions with designers, focusing on shape-changing interfaces, interaction, and functions for an AI personal assistant for online clothing shopping. From there, three concepts emerged, each with a unique set of shape-changing abilities, functions, physical appearances, and interactions. These three concepts have been materialized in three artifacts to allow the various shape-change types and intelligent agents to be experienced. This paper's contribution is a variety of applications for various shape-change types for online clothing shopping, three design examples with experiential artifacts, and a reflection on shape-change and AI.

Author Keywords
Shape-changing Interfaces; Tangible User Interfaces; Artificial Intelligence; Intelligent Agents;

INTRODUCTION
Tangible User Interfaces (TUI) have the advantage that they make use of our haptic senses and peripheral attention and give us the possibility to manipulate the information at the same time [19]. This is different from ordinary Graphical User Interfaces (GUI) where all data is on a screen, for example, on our laptop. In addition to the TUI, Ishii's vision of Radical Atoms has emerged, in which dynamic physical materials can be manipulated in order to manipulate digital information directly [20]. Where it went from a projection on a tangible object to visualize the data, it now explored with materials that could possibly change shape in order to display the data. This means it goes from stately and passive TUIs to dynamic and active shape-changing TUIs to see the data change, manipulate it, and perceive the manipulation. As a result, shape-changing interfaces emerged, with especially many visions and futuristic thoughts [38, 47, 48]. Shape-changing interfaces are interfaces that use a physically changing shape as input or output from user [39]. Within the research world there has been a lot of focus on the technical, feasible side of shape-changing interfaces [39]. However, the dangers and ethical aspects should also be extensively considered, and reseachers need to consider the challenges of integrating shape-changing interfaces into our daily lives [4]. Therefore, it is interesting to explore in which contexts shape-changing interfaces can bring value to users and how this is experienced. This can be done by making the future visions of shape-changing interfaces tangible and experiencable, one of the main focus points of this study.

Furthermore, an interesting application for shape-changing interfaces is Artificial Intelligence (AI). AI can make recommendations, detect anomalies and automate systems by classifying data and detecting patterns in complex and large data sets [11]. Making AI understandable has various advantages, such as trust [36], as well as better influencing and improving the intelligent system [**?**]. Interactive Machine Learning (ML) techniques provide transparency and interpretability of the model to the users [40, 45, 46], which means that interaction with AI has major advantages within Explainable AI (XAI) [10, 53]. A type of interaction that has been less explored within this area and may be of interest is Tangible Embodied Interaction (TEI) [15]. This can make a connection with shape-changing interfaces, which are often used for data physicalization [14, 22]. An interesting overlap here is the data used for the models of AI could be the same data that is manipulated by interacting with TUIs and shape-changing interfaces. This would allow the data manipulation and its result to be directly observed. This data physicalization and embodied interaction of AI using shape-change offers possibilities to interact directly with the data and to make AI more understandable and transparent. In addition, shape-change uses temporal form [4], something that intelligent systems also have, as it obtains more data and therefore learns more about time. These connections represent a new interesting area in which this research tries to make a first draft in order to give a different view on Explainable AI and shape-changing interfaces and to move towards Tangible and Graspable AI using shape-change.

A context in which tangibility and physicality are often missed is shopping for clothes online. This mainly concerns touching the items [31], and touch is an important sensory modality for obtaining relevant product information. Furthermore, this influences the product evaluation [12, 32] and the customer decision-making [27, 33]. While in physical stores, the customers can experience and put on the item, on online websites, the customers can only judge the items by images. This is one of the reasons why many items are returned [9, 52] and why customers remain hesitant to buy these items online [6, 7, 17]. In addition to the intangible challenge, a lot of AI is integrated into online shopping websites to improve customer experience, satisfaction, and loyalty [28]. When shopping for clothes online, this mainly concerns the customization of the website by collecting data from the customer [42]. This can include looking at all the clothing the customer has already searched for, previously purchased items with the corresponding size, or for example, styles and colors. Furthermore, there are chat-bots that can help customers find the item that they are looking for by making recommendations and looking at previously purchased items [42]. This combination of the digital world, the lack of tangibility in this context, and the extensive use of AI by various online shopping websites make this an interesting research context to investigate the opportunities of tangible AI.

The aim of this paper is to explore tangible intelligent agents in the context of online clothing shopping with shape-change through a research through design process [42]. This is done through co-design sessions where designers create tangible personal assistants with shape-change, with a focus on function and interaction. The novelty here is designing with different types of shape-change within a certain context. Ultimately, three concepts emerge from these co-design sessions, which are presented by means of a scenario, and the Artificial Intelligence and Shape-change within these concepts are examined. Eventually the concepts are made tangible in the form of three artifacts, in order to be able to experience the shape-change and the tangibility of the intelligent agent in this way. These artifacts are evaluated during a short demo, at a design exhibition, where the three artifacts can actually be experienced and voted on. The contribution of this paper is different applications for different types of shape-change for shopping clothes online, three design examples with experiential artifacts and a reflection on the use of shape-change for intelligent agents.

RELATED WORK

Prior work has already explored the tangibility of AI, such as physical intelligent robots, which often involves a physically humanoid robot that can make its own decisions with human-like behavior [18, 13, 29, 23]. However there are many different types of robots, in various physical forms and expressions, such as shape-changing robots [44] or social robots [16]. The boundaries are intricately close together and there is something to be learned from each part within the field of making intelligent agents tangible through shape-change. An example of a social robot is a robot that can communicate its emotions through texture change [16]. The user can experience these emotions by seeing the texture change as well as by touching it with the hand. Another more abstract example is T.A.I. [26] where it is all about tangible and physical human-AI communication. T.A.I. is made of shape-change, namely volume change, to add an extra layer with the digital communication of the user and conversational AI agent. This shape-change is incorporated on the back of a telephone with which the user communicates digitally with the AI agent. This research shows that the tangible, and with it a different modality, provides empathy and social connection with a virtual intelligent system. These examples show where shape-change can be useful as tangible output for intelligent agents. Both provide interesting insights that can be viewed in different contexts within shape-change and AI. Another example of a different context is the energy context, for which Ripple [49] a smart thermostat is made. This is not only about haptics but also about the visual aspect. Ripple uses shape-change and is a rotary knob that can expand and collapse and the different movements allow Ripple to express positive and negative emotions. This provides new insights into the use of shape-change movements for the behavior of an intelligent system. Where Ripple has clearly made a start where shape-change can help to make everyday intelligent objects more intuitive and intelligent.

An example of a tangible intelligent agent in the context of online shopping is Amazon's Echo Look [34]. This is a hands-free camera, which is a personal styling assistant. Amazon's Echo Look is physically made so that there are sensors, such as the camera and microphone so that information can be collected from the user. In addition, a speaker is included so that output can be delivered by the personal assistant by means of speech. By taking a photo of the outfit that the user is currently wearing by means of the Echo Look, the user can keep a Lookbook. In addition, the user can request style advice from the Echo Look after they have taken a photo.

CO-DESIGN SESSION

This study on making intelligent agents tangible in the context of online shopping focuses on three main research questions:

1. What are the functions of an AI personal assistant for shopping clothes online when made physically using shape-change?

2. In what ways can an AI personal assistant be made tangible and physical for shopping for clothes online?

3. How can there be an interaction with the AI personal assistant for shopping clothes online when made physically and tangible?

Multiple co-design sessions were held with designers from different backgrounds to answer these questions. The method of co-design session was chosen as generative tool to explore with different shape-change types. By making many physical and tangible creations with different designers, several concepts can be quickly devised and several different explorations can be made. The co-design sessions aim to prototype a physical and tangible personal assistant for shopping clothes online, focusing on function, shape-change, and interaction.

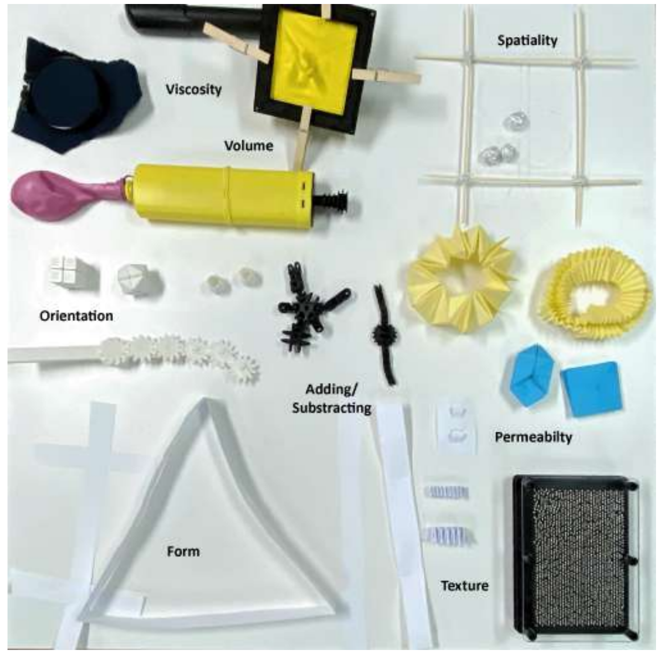

Figure 3. Quick prototypes of the different Shape-change types based on [39].

Participants

There were four co-design sessions, one pilot session with two designers, and three co-design sessions with four designers, with a total of 14 designers. The participants were designers with different expertise, all with an academic background in Industrial Design. From interaction designers to social designers and from user experience designers to designers who focus on prototyping and programming. Some were still students, and others are full-time employed. The age of the participants ranged between 22 and 31 years old, with eight males and six females. These participants were chosen because they have experience in online shopping. In this way, a combination has been made between user and expert, whereby the designers have knowledge of shopping online and as well have knowledge about designing and prototyping.

Figure 2. Two participants prototyping together during the co-design session.

Procedure

The co-design sessions were conducted in large rooms with several tables, where there were two large tables with craft materials and tools, such as scissors and glue. The participants were allowed to use all materials, tools, and space to stimulate creativity. In addition, there was a table where the participants could experience different shape-change types based on [39] through quick prototypes made by the researcher, shown in Figure 1. The shape-change types are: orientation, form, volume, texture, viscosity, spatiality, adding/subtracting, and permeability. All participants signed an informed consent form explaining the co-design session before the session started. The researcher led the co-design sessions, gave instructions, kept track of time, and took notes. Participants were free to use different tables or seclude themselves to create a pleasant workplace. The co-design sessions consisted of three parts; preparation, analysis, and creating.

The first part of the co-design sessions is the preparation. All participants received a booklet in advance in which they had to answer questions about their online shopping experience. They were asked to review their online shopping scenario and to go shopping for example for a shirt online. The booklet's purpose was to familiarize the participants with shopping for clothes online, make them think about it, and prepare them for the co-design session. Questions in the booklet were, for example, the reasons for shopping for clothes online or what they thought were essential filters when shopping online.

In the second part, the analysis, the physical co-design session started. First, the participants were randomly divided into duos and asked to complete a customer journey map [41] of their online shopping experience. This stimulated a joint discussion about shopping for clothes online and exposed at the differences and similarities between the participants. The customer journey map aims to get an overview of the challenges when shopping for clothes online. After completing the customer journey maps in duos, the participants were asked to come to the table with the rapid prototypes of the different shape-change types based on [39]. Here the participants could experience the different shape-change types, which could help them incorporate a shape-change type into their tangible prototype.

The last part is the creating phase, where participants were asked to create a tangible and physical personal assistant for shopping online clothes with shape-change. The creating phase also consists of three sections, where they get the opportunity to pitch their prototypes to each other after each section. In the first section of the creation, they were asked to work in the same pairs as the customer journey map to create a tangible personal assistant for the problems they found while completing the booklet and customer journey map. After the participants had made the first iteration and pitched it to other duos, the researcher gave them a scenario card. This scenario card describes a specific item of clothing that needs to be found online using their made artifact. The participants randomly draw a card, one card per duo. With the card, they were stimulated to go through the scenario with their tangible artifact one more time and to improve their prototypes based on this scenario. This is followed by the second pitch round after the participants receive an interaction card based on the Interaction Frogger Framework [51]. The participants had to pay attention to their interaction with the tangible personal assistant and improve it based on the card. This card is also taken at random and may not be exchanged. In this way, the participants were stimulated to look at their creations differently and pay attention to other parts of their design, such as the interaction and the scenario that it supports. After this round, the final results are pitched together with the background story, consisting of the customer journey maps, challenges, type of shape-change, function, and interaction. Video recordings were made of these pitches, and they were allowed to portray the situation to get a better picture of the concepts. Finally, these videos were transcribed and observed by the researcher.

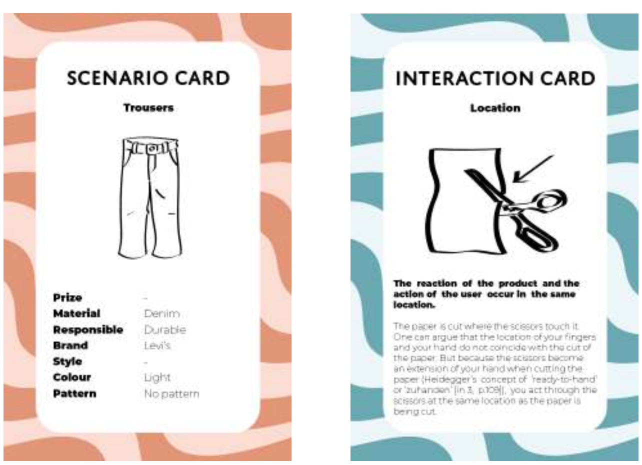

Figure 4. Example cards of the scenario cards and interaction cards based on [51].

Pilot Co-Design Session

First, a pilot study was performed with two designers who had to make a prototype individually. The rest of the procedure was the same as described in the previous section. The resulting prototypes are illustrated in Figures 5 and 6.

Pilot Prototype 1

This prototype is the "Fabric Balloon", a sphere that can inflate and deflate with a fabric wrapped around it to show how the fabric drapes over the body. The balloon represents the body and can physically show how a piece of fabric, for example, falls nicely smooth or whether it has for example ironed creases. The user can activate it to pull the sphere up, causing it to inflate, and the user can then rotate it to view different fabrics. The user can also push it back down to deactivate it, causing it to deflate and collapse.

Figure 5. Demonstrating the tangible pilot prototype 1, "Fabric Balloon".

Pilot Prototype 2

This prototype is "Lock & Go", which are blocks on each a screen to visualize an individual piece of clothing. In this way, the user can make sets with each block, that represent a piece of clothing. If the user would like a SALE item, the assistant can make different sets with it by placing different items of clothing on the blocks with the SALE item. To place an item in the shopping cart, the user can push the block backward and thereby lure the item. In this way, the user has an overview of what is already in their shopping cart. Furthermore, the assistant can make other suggestions for sets with the items already in the shopping cart. The personal assistant makes these suggestions by showing the other blocks near that locked item to create new sets.

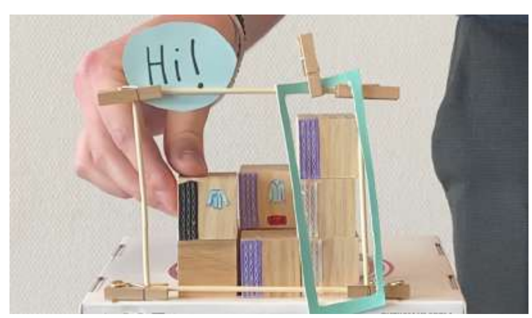

Figure 6. Demonstrating the tangible pilot prototype 2, "Lock & Go".

A major learning point from the pilot study was that designing with shape-change was still seen as a challenge and that this was very difficult on an individual basis. The participants would have liked to have had a fellow person to discuss designing with shape-change. This is the reason why the final co-design sessions were held in duos, as well as stimulating more creativity. In addition, questions have been made clearer in the booklet to indicate that it concerns personal experience and personal interpretation.

RESULTS

This section presents the tangible prototypes, considering the function, physical appearance, interaction, and type of shape-change.

Tangible Personal Assistants Prototypes

Twelve participants in duos created six different tangible personal assistants. The participants presented their prototypes with their motivations and showed their interactions with the created personal assistant. In addition, they were also commissioned to come up with a name for their prototypes. The prototypes are illustrated in Figures 6, 7, 8, 9, 10, and 11 and are further described in the following sections.

Prototype 1

The first prototype is "De Pashulp", a strap that helps to find the right clothing size. This strap can be worn on any part of your body to measure the size. It can physically show the clothing size by physically indicating with the strap what the size of the garment online is by changing in size. This can be useful if the user is unsure between two sizes, for example. In addition, It can be used as an extra filter function by indicating the measure being searched with the strap. Ultimately, the idea is that the strap can stretch on all sides and could also mold around the body. The type of shape-change used here is volume change.

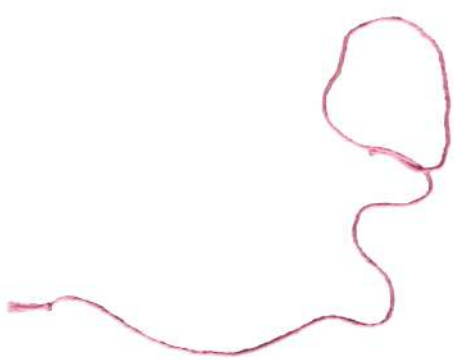

Figure 7. Tangible Prototype 1, "De Pashulp".

Prototype 2

The second prototype, "Pauw," is a circle with colors made from a fan that helps search for clothes online. The user has a specific search profile that they set in advance. Three important values can be set such as durability, style, and budget. These three categories are displayed in the round fan, and when you search for clothes, the fan changes to different colors. For example, if a t-shirt is durable but does not fit the user's style and is not within the budget, the fan will only show the color of durability. All three colors will be shown if the garment meets all three requirements. During the search, the user can make the color areas larger or smaller to indicate that they find this value more important than the other values per item of clothing. In this way, "Pauw" continues to search for garments with these values. The shape-change type used here is orientation/form.

Figure 8. Tangible Prototype 2, "Pauw".

Prototype 3

The third prototype, "Ubofi," is a scaled-down model of the user's body. A fabric falls around the model to see what the garment would look like on their body. When the user scrolls through the website looking for items, they can select an item and see on the model how the garment will fit their body. The fabric is then pulled looser or tighter around the body. In addition, the top of the model has a surface that can change texture and material. In this way, the user can experience the material of the particular garment. The type of shape change here is volume change and texture change.

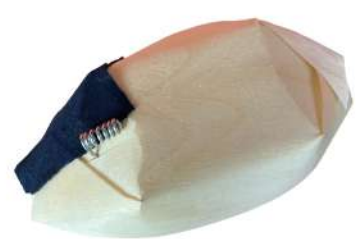

Figure 9. Tangible Prototype 3, "Ubofi".

Prototype 4

The fourth prototype, "Fabrizi-use," is a computer mouse that indicates how a material feels from a garment displayed online. The index finger side of the computer mouse changes to different textures. In this way, the texture of the garment that the user would like to purchase can be experienced. This can be about smooth or rough but also stretched or stiff fabric. The shape-change type used here is texture change.

Figure 10. Tangible Prototype 4, "Fabrizi-use".

Prototype 5

The fifth prototype, "Zzzsmorphefi", is a shape-shifting sofa with a blanket. The couch and the blanket can register the user's behavior and thus recognize whether the user is comfortable shopping online. If this is the case, a fashion show hologram will start, and models will be projected past it as the user sits quietly on the couch. Then, the user can get off the couch and look closely at the hologram models. Ultimately, the model can be taken to the couch to be able to buy the item. In addition, the couch and the blanket register the user's behavior, and with that, it can also know whether the user finds the items boring or becomes grumpy that there are no garments that match their desires. In this way, the system can eventually renew the garments to display the correct clothes for the user. Finally, the couch can move; for example, try to get the user off the couch to get a closer look at something if it thinks it's the perfect item for the user. The type of shape change here is the volume change.

Figure 11. Tangible Prototype 5, "Zzzsmorphefi".

Prototype 6

The latest prototype is "Blueino," an assistant that helps users search for clothes. It is half a fan including a conductor and a pointing stick, which invites the user to explore beyond what they usually search for outside their categories. Next, the user can interact with the fan to lock or mute categories, which is done with the conductor. This way, the assistant knows which categories to look in and which not. Finally, it will show different categories, and the user can let "Blueino" know what they think of the suggestions. If they are the right suggestions for the user, the user can close the fan with their hands, and then the fan will slowly open with new suggestions. The shape-change type used here is orientation/form change.

Figure 12. Tangible Prototype 6, "Blueino".

Analysis of the Prototypes

Each prototype was put in a table (pilot prototypes not included), see Figure 13, where attention was paid to different aspects, namely: problem, function, type shape-change, interaction, AI, physical form, and realistic. Where interaction is about the magnitude of physical interaction with the body, hand or finger and realistic is about whether it is currently feasible or is expected to be in the future. This provided an overview of the essential properties of the prototypes and made it easier to establish connections. In the end, colors are used within the table to show the connections between the different aspects. A diagram has been made of this to show the most evident connections, such as the type of shape-change that had to do with the function as well as the physical appearance. These important aspects as well correlate with the three research questions formulated at the start of the co-design sessions. In Figure 14 the diagram with the relationships is illustrated, along with the prototypes made from the co-design sessions. Here it is visualized that the shape-change volume type is linked to the function fitting, the texture type to the experience of materials, and orientation and shape to the search for the clothing. Furthermore, volume that is matched to fitting, is linked with an individual detached object, which means that the participants with both volume as shape-change type and fitting as function made an individual detached object. Next to that, texture matched with experiencing materials, is integrated into an existing, such as the prototype “Fabriziuse”. And lastly when using the shape-change type orientation/shape the function was search and an independent new body was used.

	Problem	Functions	Type shape change	Interaction	Physical form	Realistic
Pashulp	Difficult to estimate fit	Estimate fit	Volume	Body / hand	Tool	Now
Pauw	Trouble with searching and need for style advice	Searching	Orientation / Form	Hand	Body	Now
Ubofi	Difficult to estimate fit	Estimate fit	Volume / Texture	Hand / finger	Body/Tool	Texture change / body scan
Fabrizi-use	Do not know how a material feels	Feel materials	Texture / (Viscosity)	Finger	Integrated	Texture change
Zzzsmorphefi	Not comfortable to shop	Searching	Volume	Body	Integrated	Hologram
Blueino	Trouble with searching and need for style advice	Searching	Orientation / Form	Hand	Body	Now

Figure 13. Table with the created prototypes of the co-design session with the six important aspects.

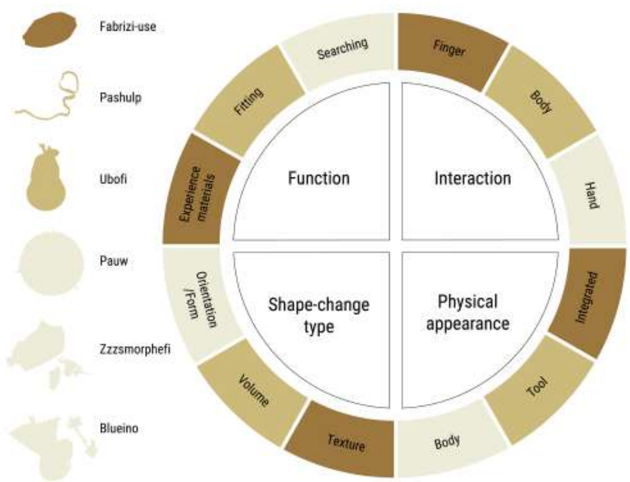

Figure 14. Diagram with the four important aspects and the connections made with the analysis on the table in Figure 13. The colors are linked to the prototypes.

THREE TANGIBLE INTELLIGENT AGENTS

During the co-design sessions, various concepts and prototypes were conceived and made. Interesting patterns have been discovered during the analysis and the four main themes of this research have been extracted, namely: (1) Function, (2) Type of Shape-change, (3) Physical Appearance, (4) Interaction. Within these four themes, three concepts can be devised whereby the four themes remain linked. In the next section, three different concepts of three different intelligent agents are explained that originated with inspiration from the co-design sessions and with the help of the created diagram of the analysis. The speculative scenario, the Artificial Intelligence, and the type of shape-change is described per concept.

The Mouse

The first intelligent agent, "The Mouse", is derived from the shape-change type texture change, whose function is to experience the materials, where the physical appearance is integrated and the interaction with the finger.

Scenario

Viv is looking for a jacket online on several websites. She has been looking for a super soft jacket for a while; however, she can not see and experience the materials in the pictures. She grabs "The Mouse", the intelligent agent, a mouse cover for her computer mouse. Viv puts it over her computer mouse, and the mouse is immediately activated. She notices this by the vibration she feels in her hand when she touches the mouse. With the mouse, Viv navigates to several jackets on the website she had already found. When she hovers her mouse over a jacket on the website, the mouse's bed on which her index finger rests changes from material. This allows her to feel how the material of this jacket feels on the mouse. However, she is not yet satisfied with how soft it feels. She activates the scroll wheel on the side of the mouse by tapping the side of the mouse twice. This makes a scroll wheel appear on the thumb side of the mouse with which she can scroll through the materials. The mouse already knows that she is looking for a soft fluffy jacket because she is already looking at them. This means that the materials of the scroll wheel are automatically soft. She scrolls through the materials with her thumb until she finds something that she finds soft enough. She rests her thumb on this and she sees the website where she was looking for a jacket loading. Several jackets appear on her screen, all of which have the material she selected with her mouse. She sees one in her favorite color and orders it immediately.

Artificial Intelligence

This scenario shows how the shape-change type texture change can be used in an intelligent agent. Here, the AI part could be the material recommendations made by the intelligent agent. These recommendations can be made based on, for example, previously purchased items, search terms, style, or wardrobe. Allows the agent to make tangible material suggestions on the physical mouse. As the agent is limited to showing only a few materials in a particular range, it is also essential to learn whether it is showing the suitable material. It could learn how people experience materials to convey the right experiences. In this way, the intelligent agent can convey the right experiences of the garment's fabric with a limited number of textures and materials. In addition, it involves a bit of behavioral recognition, where the agent recognizes by the way the mouse is used or by feeling the material what the user thinks of the piece of material. Based on this, the mouse could make new physical material recommendations.

Shape-change

Within shape-changing interfaces, there have already been several studies in the field of texture change [25, 21]. The best known in this area are the multiple pins that change the surface by going up or down, and therefore the texture [25, 21]. However, this is not material change, and the shape-change used here within this concept. In addition, there are possibilities to work with more powerful motors with larger spinning discs and mechanisms to show different materials. However, the materials are then limited to only a small amount, and not all sorts of materials will fit on the constructions due to the limited amount of space available. Furthermore, the mouse is also built compact and small, and these mechanisms would not fit in this housing. In addition, it might also be possible to look at inflatables. An example of this is the work of Hu and Hoffman [16], where skin texture change in social robots is used to feel different emotions. Different textures are activated, by blowing up a different part each time. Another example is holding different plate holes in front of the inflatable in different shapes so that it blows out in different texture patterns [54]. However, this is also limited to only a small amount of textures, and this system size is too large for a computer mouse. Furthermore, this concept is mainly about haptic sensation, which has already been researched more [8, 5]. The involved parameters of experiencing and touching a piece of cloth or other materials should be further examined. For example, the work of Volino at el. has done [50], could be used to realize the envisioned material change on this small scale. For example, the work of Volino at el. has done [50] where they look at the perception of fabrics, which could be used to realize the envisioned material change on this small scale

The Snake

"The Snake", the second intelligent agent, is derived from the shape-change type volume change, whose function is to find the right fit, where the physical appearance is a loose tool and the interaction with the body.

Scenario

Vic sees several baggy pants on his phone on social media. This are pants that should be a bit looser but not completely sagging. He would like to buy one because this is fashionable now. However, he doubts about the size of the pants and that is why he is bringing in his intelligent agents, "The Snake". This is a band that he puts around his waist at the height of where he wants to wear the pants. By stretching the band, he can make it bigger and by pushing it together, he can make it smaller again. He plays with the sizes of the band a bit until he thinks he has found the perfect size for the pants. This is it, Vic thinks, the band is very loose but it has not fallen off my hips yet. He looks at his phone, and and sees that "The Snake" confirms his choice. On the clothing app all different baggy pants appear in the size he just indicated. He scrolls through the pants looking for a black one, and puts it in his shopping cart.

Artificial Intelligence

This scenario shows how volume change can be integrated into an intelligent agent. It contains three interesting levels of intelligence, two of which overlap with "The Mouse". Starting with the recommendations, where by looking at previously purchased items and previously purchased items from other customers, the agent would be able to suggest the size of a particular item of clothing from a particular brand. Sizes seem general, but they are not because there are different models, brands or ways that it can be worn. "The Snake" can thus be used to personalize the size of the user and make recommendations based on the preferences of how the users likes to wear clothes. Furthermore, just like with the mouse, there is a bit of behavioral recognition in which it knows when a measure is confirmed or if the user does not come out. In this way the agent can help to show the right items or help with finding the right fit. In addition to these two techniques, recognition is also needed of where the band is on the body. In this way, the intelligent agent knows which part of the body is being viewed and can therefore make the correct recommendations of items for that body part.

Shape-change

There are several possibilities to change the volume, as required for this concept, such as inflatables [24] or by joining objects [30]. In addition, one can look at elastomers [37], such as silicone, something that could also be inflated. A specific category related to elastomers are Auxetic materials [37], where it is more about stretching and contracting a material. The material widens when stretched and shrinks when compressed. This is due to the internal structure, such as honeycomb structures, where the sides of the hinge-like cells expand outward when stretched. This concept is a good solution to be able to play with the material and still change the surface of volume. However, it should be examined how this should be actuated. However, only one study was found in which this was applied [43].

The Peacock

The last intelligent agent, "The Peacock," is derived from the shape-change type orientation/form change, whose function is to help with searching, where the physical appearance is a new body and the interaction is with the hand.

Scenario

Val would like to shop more sustainably, because of the large amount of clothes that she shops for online, but she also wants to buy second-hand clothes or clothes made of recycled material. She has a lot of trouble with how to approach this, and she often continues to order too much. She recently bought a new intelligent agent, "The Peacock", to help her with this problem. This one is on her desk next to her laptop and helps her make choices while online shopping. In her case, specifically sustainable choices. During her lunch break, she looks *for a summer dress for her birthday. When she opens the website of her favorite brand, her intelligent agent is activated and this can be noticed by the opening of the curve. She searches for different floral dresses and comes across one she has been looking at for a while. From the corner of her eye, she sees her intelligent agent moving slowly back and forth to get attention indicating that it might not be the perfect match based on her personal shopping goals. It goes up and down a bit. She looks at the dress and sees that it is a new dress, so not second-hand and not made of recycled material. She really likes the dress, and it's for her birthday, so determined, she grabs her intelligent agent and closes the curve. She searches for her size and puts it in her shopping cart. Slowly the curve of the intelligent agent opens again and moves from left to right. Different pop-ups appear of approximately the same dress, but then second-hand or from recycled material. Val clicks on one that's about the same color she saw. This one is second-hand and cheaper too! She puts it in her shopping cart and removes the other dress. She gently strokes the outside of the intelligent agent to thank him. She happily pays for the dress and closes her laptop. "The Peacock" goes back to sleep and closes its curve.*

Artificial Intelligence

This scenario shows the combination of orientation/shape change with an intelligent agent using it as a personal assistant. The agent learns from the user based on all information such as calendar, bank account and previously purchased items. In this way, it can make recommendations based on knowledge about the users motivations and preferences and help with online shopping behavior. The interaction with the intelligent agent creates a feedback loop, from which the agent can learn even more to help better next time. By tweaking the weights of all these different factors, the learner can make predictions, unlearn behavior and make recommendations. Every "Peacock" of every person is unique and different because it is fed with different data per person and every person has different standards, values and goals. Certainly within the online shopping of clothes, fashion is taste objective, however "The Peacock" should be able to learn the taste from its user.

Shape-change

A challenge in terms of shape-change here is that the input and output are on the same actuator. This means that the actuator must be strong and have sensors to be able to do the movements of the curve, in addition to perceive the input of the user and to be able to handle this force. One approach to achieve this, would be to measure the electrical current used by the servo motors. If the current unexpectedly changes, the system can assume that a user is touching the origami curve as the shape is being blocked/held. If the system would detect such an event, it should immediately power off the servo's to prevent the user from damaging them. After the curve has been idle for a while (measured by the integrated potentiometer), the system can assume that the user has let go. Another approach involves the use of Capacitive Sensing, something that is also used for example with Lumen [35]. By integrating conductive yarn into the origami curve, touches by the user or even proximity can be measured by the system. This would allow the system to turn off the servos even before they are being touched or blocked.

DEMO

This research aims to explore the tangibility of intelligent agents and the experience with different types of shape-change. This is why the three concepts have been made tangible through three artifacts. All three artifacts were based on the three concepts with the three different shape-change types. This section explains how the three prototypes work, the demo set-up with the prototypes, and the (preliminary user) demo study with the results.

Three Artifacts

Three artifacts were created to make the concepts with the corresponding type of shape-change experienceable. This was done to illustrate the possibilities with shape-change, as previous research on shape-change still lacks how it is integrated into our daily lives and what the user experience is within a context. By making the different types of shape-change experienceable in this way, it is possible to evaluate in the field of experience, ethics, and applications.

All three artifacts are linked to the same Processing [3] interface for the demo study so that the three artifacts can be experienced one by one by the user. The Processing interface is a counterfeit clothing website that searches for pants. The interface is shown in Figure 18 and is a static interface, which does not allow for navigation to other pages. In addition, an interface has been built to switch between the artifacts. In this way, the artifacts can be activated alternately or simultaneously. The three different tangible artifacts are described in the sections below and are shown in Figure 15, 16, and 17.

Artifact 1

This artifact consists of a 3Dprinted case made of PLA that fits exactly around a wireless computer mouse. In addition, a 3D-printed cover is also made of PLA for the case in which the electronics are processed. The electronics consist of a Teensy 4.0 [2] and a micro servo. For the micro servo, a turntable attachment has been made with three different fabrics on it, on the quarter of the turntable. A 5V, 2A, the additional power supply is used to power the servo.

The different quarters of the servo's turntable, with the three different materials, are linked to the images of the Processing [3] interface. When the mouse is hovered over a certain image, the corresponding material from the turntable is shown through the hole on the index finger side of the mouse case. In this way, the user can feel with their index finger per image how the material of the particular garment feels.

Artifact 2

This artifact consists of a band with a clip and a small swimming armband with a fabric stretch cover. Attached to the swimming armband is a silicone hose that leads to a box with the electronics. In the electronics box is the circuit with Arduino Uno [1], two pumps for blowing air, and a large vacuum pump to suck the air out of the inflatable. In addition, there is a valve so that the air cannot run away while the system is not used and idle and the power is regulated with a DC-Motor

Figure 15. The artifact 1, "The Mouse".

Controller. As the small pumps require less power (5V) than the large vacuum pump (9V), the power is converted by a Step-down Converter. There is also a pressure sensor to measure the air pressure in the swimming armband.

The band with the inflating and deflating bag is also connected to the Processing [3] Interface. Here all the sizes are the same, however the brands are different. The bag will inflate or deflate by hovering over the sizes of the images of the garments. By inflating or deflating the bag, the band becomes smaller or tighter when the user wears it. In this way, the user can experience the specified tangible size of the garment and how it would fit.

Figure 16. The artifact 2, "The Snake".

Artifact 3

This artifact consists of a 3D-printed cylinder made of PLA. The cylinder has a flat bottom part to ensure the stability of the prototype. The electronics are fixed to the bottom of the PLA casing as well and consist of an Arduino Uno [1] and two high-torque servos. An additional power supply of 9V and 2A was used to power these servos. A 3Dprinted attachment was made for the servos where fabric can be clamped into. There is also a hole in the cylinder where these attachments can come out of. A piece of polyester fabric where origami structures of PLA are 3D printed on top, is folded in these origami structures and clamped between the two servo attachments.

This artifact is also connected to the Processing interface, taking into account the price. When the mouse hovers over the images, the servos move and behavior is displayed via the fabric (shaped by origami patterns) on the cylinder. For example, when the price is within the budget of the user, which the user may experience as pleasant, the artifact will do calm and happy movements. While if the price is above the budget of the user, the artifact can make a startle move or warning move.

Figure 17. The artifact 3, "The Peacock".

Demo Study

These three artifacts were demonstrated at a design exhibition at a technical university. Several people came by, mainly students and teachers from the university and external visitors from outside the university. During this exhibition, the three artifacts could be experienced individually, and the various artifacts were also explained as intelligent agents with text on three separate posters. After the trial, the participants could vote for their favorite intelligent agent. This was based on the function and the shape-change type. In addition, the researcher asked why this choice was made and whether they could explain their considerations. In addition, attention was paid to the first reactions of users in order to observe and

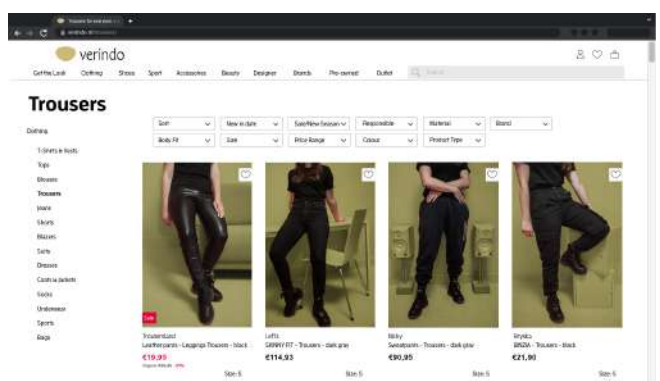

Figure 18. The created Processing Interface.

evaluate the first experience with the shape-change type. The researcher kept a number of comments and wrote them down during the experience and questions. In this way the first thoughts of the users become clear and a preliminary study has been done in the field of making intelligent agents tangible and especially in the field of shape change.

Result Demo Study

Ultimately 46 participants experienced and voted on the three artifacts. During the voting process, there were two apparent differences, the mouse and strap were seen more as pragmatic products, while the origami cylinder was seen more as an assistant. Here is a quote from a participant about Artifact 3, the fan: *"This one is really open to interpretation, and the other ones more concrete."* and another quote about the same artifact from a different participant: *"I don't need an extra friend to make a decision about my clothes."* Another quote about all the artifacts from a different participant: *"With the inflatable I feel more what is happening, also with the mouse and I need less of that abstract."* Another quote about artifact 1 from a participant was: *"Useful when I close my eyes."* An observation during voting was that the participants often hesitated between artifact 1 or 2, the two pragmatic products. In contrast, most participants who voted for artifact 3 often cast their votes immediately. With the voting, there has been a total of 46 votes, Artifact 1, "The Mouse", received the most votes: 20 votes, Artifact 2, "The Snake", received 14 votes and artifact 3, "The Peacock", received 12 votes. With the last one, artifact 3, there was also something written on two voting cards, namely, at voting card one: *"It could be my shopping buddy" and on voting card 2: "Nice that it is abstract."*

Looking at the first experiences of the different types of shape-change, starting with Artifact 1, "The Mouse", many users were remarkably enthusiastic about the experience. However, one participant immediately said: *"Oh, my finger is being sucked all the way."* In addition, another participant was reluctant to experience the artifact because they were afraid of what was to come and did not know how to use it. Artifact 2, the band, was experienced by visitors in different ways. Not all participants put this on their waist, however some saw it being worn by another person and/or felt it on the inflatable pillow. There were several reasons, such as the band being close to the table, time, and uncertainty. In addition, one participant said, *"You can murder someone with this."* Furthermore, the band was mentioned by several participants that the band feels like a kind of massage for the back. The last artifact, artifact 3, "The Peacock", intrigued many participants by the opening and closing movements it was constantly doing before any interaction took place. This has already attracted much attention from visitors. However, several participants also discussed the different movements and how they were related to certain things, such as being within or outside the budget. There was also one participant who found the movements distracting. Furthermore, many participants found the movements lively, with one participant describing it as a kind of dog and several participants describing it as friendly movements.

DISCUSSION

The studies in this paper aimed to explore the tangibility of intelligent agents with shape-change. A research through design [55] method was used, in which shape-change was explored, and various prototypes were made, experienced, and three concrete examples were devised.

Co-Design Sessions

To start exploring the tangibility of intelligent agents with shape-change, a co-design methodology was used as a generative tool in which 14 designers got to work within the context of shopping clothes online. Three research questions were formulated for these co-design sessions with a focus on: the function, physical appearance and interaction with the personal assistant. The diagram made from these themes, including the shape-change type theme and from the analysis of the prototypes created, shows an interesting insight where there are three distinctly different functions. These functions are: help finding clothes online, experiencing the material and helping to find the right size. In addition, the tangible artifacts created had different physical appearances, where it can be integrated into an existing object, such as a computer mouse, it is a separate tool or a new body. The analysis was done by the researcher alone and the separate tool and new body could also be described as the same as both can be considered as two separate objects. However, the difference here is the pragmatism of the tool and the lively nature of the new body, which means that they are described in the analysis as two different elements. In the future, it could be examined how experts or users would articulate this, as well as other wording of the concepts and assistants during user and expert evaluations. However, the researcher did instruct the participants to name their concepts and prototypes. This would allow further analysis to investigate the difference in names and associated concepts to determine how the intelligent agent is perceived.

Looking further at these findings, there is one prototype co-design session that does not fit into the diagram created by the analysis: "Zzzsmorphefi". This one does address the function of helping with clothing search, although it does not overlap with the other prototypes with the same shape-change type, interaction, and physical appearance. Nevertheless, if the prototypes of the co-design sessions are included, it is interesting to see that the themes can also be linked to each other within these concepts. For example, the pilot prototype "Fabric Balloon" uses texture change to experience materials and volume change to see how the fabric falls over the body. The pilot prototype "Lock & Go" uses orientation/shape change to help make choices. Now that these connections can be made with different themes of this research, especially the type of shape-change and function, this offers opportunities to look further outside this context. Potentially, the same connections of the diagram could be made with the different shape-change types within a different digital context. In addition, the usefulness of shape-change in that context could possibly also be demonstrated here.

In addition, the level of intelligence and AI was not considered an important part in the co-design sessions. This is the reason why the degree of AI and intelligence differ within the tangible prototypes with corresponding concepts. More use could be made of this in future research in order to possibly demonstrate the relevance of shape-change and tangibility of AI. For now the shape-change type is mainly linked to the online clothing shopping function, however in the future it could be separated and looked more at the level of intelligence.

Scenarios

The three concepts created from the tangible prototypes of the co-design sessions and the resulting diagram with themes are described in scenarios. These scenarios serve as inspiration for the future of shape-changing interfaces and intelligent agents and provide insights into the use of different shape-change types and Artificial Intelligence (AI). Moreover, by analyzing AI in the three different concepts, it has emerged in what way making the intelligent agent tangible can be important. Looking at the three concepts is the addition of a new data stream whereby by making the intelligent agent tangible a new feedback loop is created from which the agent can learn. The embodiment would allow the user's behavior to be studied and learned from in a physical way by the intelligent agent. This means that it can learn from the tangible interactions, as with "The Snake", where it can learn how the user prefers to wear the garment and where. Follow-up research could make use of this by making it achievable at the level of AI and thus providing more insights into the usefulness of shape-change in combination with intelligent systems. This could go a step further to see whether there is more reliability, transparency and understandability of AI for the user by means of shape change.

Making the intelligent agents tangible in the scenarios in the digital world of online shopping can be compared to the physical shopping experience. Starting with "The Mouse", which is about experiencing the materials, something that customers can do if they were in a physical store. More research could be done to see how the fabrics can be realistically crafted to match the physical store experience. The second scenario, "The Snake", can be compared to trying on clothes in the store. The customer can experiment with the sizes and choose the favorite fitting. Finally, in the last scenario, "The Pauw", it could be compared to the employee in the store or, more realistically, a human personal shopping assistant. These comparisons can show that what is often in a physical shopping experience and people are used to can be useful to the digital experience.

Three Tangible Intelligent Agents

Furthermore, because this research revolves around tangibility and the experience of shape-change, the three concepts were ultimately made tangible in the form of three artifacts. These three tangible and physical artifacts with the focus on different shape-change types can be taken as inspiration in the field of shape-change and its realization. In addition, they are inspirational concepts within the context of shopping for clothes online. These concepts were experienced as interesting by the participants of the demo study, and through the voting and conversations with the participants, it can be seen that there is an interest in these artifacts in daily life.

An important part of the study was the participants' first experience with shape-change. While the majority of the participants were enthusiastic about the use of shape-change, there are also ethical aspects to it. For example, there were two participants who clearly identified the dangers of the two shape-change types, texture change and volume change. In case of the texture change, it felt like the finger was being sucked through the hole where the material changed. However, this did not happen, but could be made safer in the future by having the servo change position more slowly so that the material shifts slowly. With the volume change, one participant said it could murder someone. This is a good point to consider and also an important part that people often fear about AI. If intelligent systems are made physical and tangible, like robots, and they have the power to change things in the physical world, this can be seen as scary. Especially with a strap that comes very close to the body and can be pulled way too tight and the user does not have total control over it. Future research could look at all ethical aspects within the subject of shape-change and AI in order to properly integrate shape-change combined with AI into our daily lives and reduce anxiety in people.

The three artifacts have been demonstrated with a preliminary study, as a demo, to users in order to allow them to experience the shape-change types and to demonstrate the usefulness of shape-change within this context. This is only a small setup towards a large study where the three artifacts are evaluated. The continuation of this research would be a larger user study where more research can be done on the experience of shape-change and the usefulness of shape-change. In addition, another study could be done to more clearly compare the three artifacts, as the results are still superficial.

Furthermore, an interesting follow-up study could be how the movements and behavior of "The Peacock" can be interpreted by the user. This could take a step further in the usefulness of shape-changing interfaces and making AI understandable. In addition, it could be examined how the bond between the user and the intelligent agent develops over time. This involves whether the behavior is understood by the user and whether the intelligent agent could adapt its behavior to the user in order to communicate more clearly. This could be an important study in the field of shape-changing interfaces and the importance of making intelligent agents intuitive and possibly even more intelligent.

Other Future Opportunities

In addition to these insights, limitations and future opportunities and possibilities for research, there are other future possibilities that can be looked at within this research area. In this way, the research could take further turns in the field of shape-change and AI.

Interaction

An important theme in this research was interaction. Now the interactions were simple or speculative and could be further elaborated and made tangible. Furthermore, with new user studies focused only on interaction more insights could be gained in the field of interaction and shape-change.

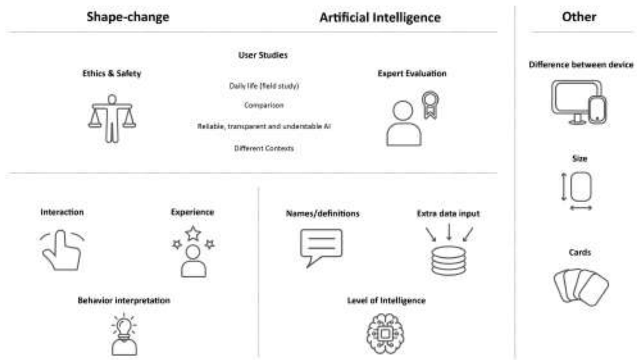

Figure 19. Future research opportunities.

Devices

In all studies, the device on which online clothing shopping is performed was not taken into account, such as phone or laptop.. During co-design sessions, the participants had their own interpretation of this and this also varied with the devices in the different concepts. In the future, it would be possible to look at a specific device or to look at the difference between the devices and to create a special shape-change artifact for a specific device.

Size

The difference in device affects the concept, but especially the tangible appearance of the tangible agent. It can affect the size of the artifact, as a phone is likely to devise a smaller artifact than with a computer. Ultimately, the size of the artifacts also affects how the users interact with the tangible object. This will range from fingertips to the entire body and will affect the data a physically intelligent agent can collect.

Interaction and Scenario Cards

During the co-design sessions, the participants were given scenario and interaction cards to make the next iteration and thereby pay attention to other aspects of their concept, such as interaction. However, they were only allowed to take 1 ticket per duo and therefore they were limited to this ticket. In the future, all interaction cards could be given to the duos to improve the chance of intuitive interaction with the created prototypes. In addition, it would be possible to look and compare how the prototypes differ from each other by means of the cards.

CONCLUSION

This work explores making intelligent agents tangible through shape-change within the context of shopping clothes online. The tangible prototypes created from the co-design sessions can be taken along as inspiration for future concepts in the field of intelligent agents and shape-changing interfaces. Furthermore, the results of this also clarify the usefulness of shape-change in the context of shopping clothes online. Ultimately, the four important themes, namely: (1) Function, (2) Type of Shape-change, (3) Physical Appearance, (4) Interaction, are linked to each other within this research, resulting in three concepts. The future scenarios with elaboration on the field of Artificial Intelligence and Shape-change are inspiration and examples of how shape-change can be combined with AI to create a tangible interaction loop to make AI transparent and understandable. The three artifacts made from these concepts, which were eventually tested in a preliminary study during an exhibition, demonstrating what the experience can be like with the different types of shape-change within a context. The combination of different types of shape-change with making intelligent agents tangible provides enough possibilities for the future to eventually be able to live in a world with shape-changing interfaces and tangible, understandable and transparent intelligent agents.

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APPENDIX

Exploring the Tangibility of Intelligent Agents through Shape-change in the Context of Shopping Clothes Online

I. INTRODUCTION

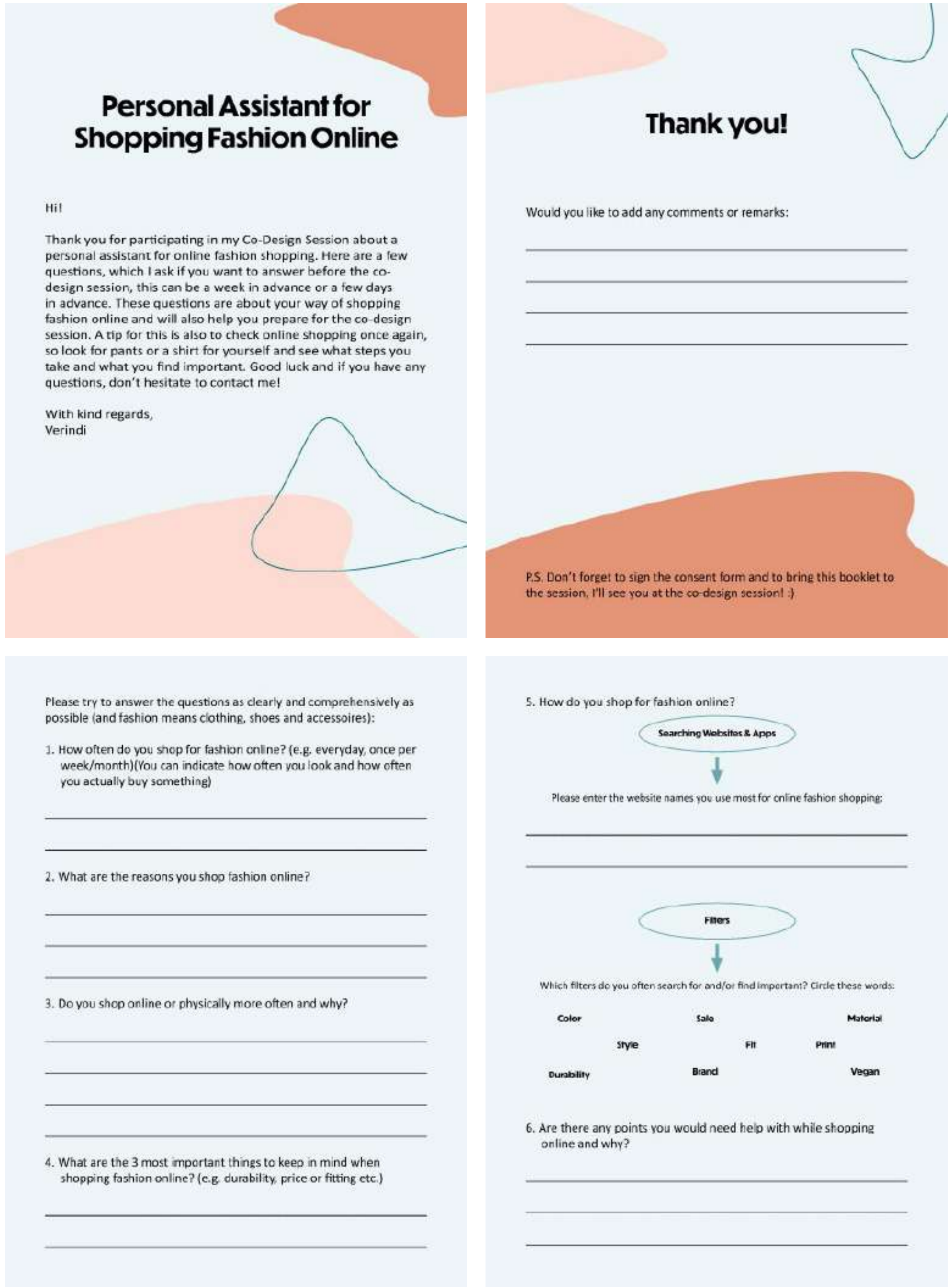
This Appendix is for the remaining part of my final master's project report next to the research paper. One of the goals of my final master's project was to write a research paper individually and thereby complete my master's in the field of research. Therefore, the appendix will mainly consist of the RDD (Research Design and Development) parts of my project that have not been addressed in the paper, The content will focus on Research & Development and Design within a business context. With this, I show skills and competencies that can be important as a designer within a company. This will mainly be about user-centered design, using co-design sessions and a customer journey map, as well as concept realization and making prototypes ready for testing.

II. CO-DESIGN SESSION

The first part that will be discussed is the co-design sessions. The goal of the co-design session was to make designers create a tangible personal assistant that helps them shop clothes online. During this study, the designers were both the user and experts on the topic. As all participants were familiar with online shopping and have personal experience with it, they can envision the challenges one might encounter from a first-person perspective. On the other hand, the participants have been previously introduced to the area of shape-change. As a result, they were able to comfortably design and prototype during the provided challenges.

A. Booklet

In order to carry out the co-design sessions as good as possible, a study setup has been designed consisting of three different phases. Starting with the preparation phase, where participants were asked to fill out a booklet that consisted of various questions about their online shopping behavior. In this way, the participants could delve into the subject and come to the co-design sessions prepared. The co-design booklet with questions can be found below in Figure A. These questions helped to collect qualitative data about online shopping challenges, the differences between physical and online shopping, and important elements that the user pays attention to when shopping online. This can be a basis for designing a first concept, starting from a challenge.



Personal Assistant for Shopping Fashion Online

Hi!

Thank you for participating in my Co-Design Session about a personal assistant for online fashion shopping. Here are a few questions, which I ask if you want to answer before the co-design session, this can be a week in advance or a few days in advance. These questions are about your way of shopping fashion online and will also help you prepare for the co-design session. A tip for this is also to check online shopping once again, so look for pants or a shirt for yourself and see what steps you take and what you find important. Good luck and if you have any questions, don't hesitate to contact me!

With kind regards,
Verindi

Thank you!

Would you like to add any comments or remarks:

P.S. Don't forget to sign the consent form and to bring this booklet to the session, I'll see you at the co-design session! :)

Please try to answer the questions as clearly and comprehensively as possible (and fashion means clothing, shoes and accessoires):

1. How often do you shop for fashion online? (e.g. everyday, once per week/month)(You can indicate how often you look and how often you actually buy something)

2. What are the reasons you shop fashion online?

3. Do you shop online or physically more often and why?

4. What are the 3 most important things to keep in mind when shopping fashion online? (e.g. durability, price or fitting etc.)

5. How do you shop for fashion online?

Searching Websites & Apps

Please enter the website names you use most for online fashion shopping:

Filters

Which filters do you often search for and/or find important? Circle these words:

Color Sale Material
Style Fit Print
Durability Brand Vegan

6. Are there any points you would need help with while shopping online and why?

Figure A. The four pages of the Booklet with questions.

B. Customer Journey Map

After this is the analysis phase, in which a customer journey map [7] was used to map the online shopping experience. This map requires participants to review all steps in shopping for clothes online, which results in a clear overview of the pain points in the online shopping experience. The Customer Journey Map is shown in Figure B and is inspired by an existing customer journey map in the field of online shopping [1]. The “Search for Websites” step has been made smaller as often users already have their favorite clothing websites or that they have already found what they are looking for with a keyword in a search engine.

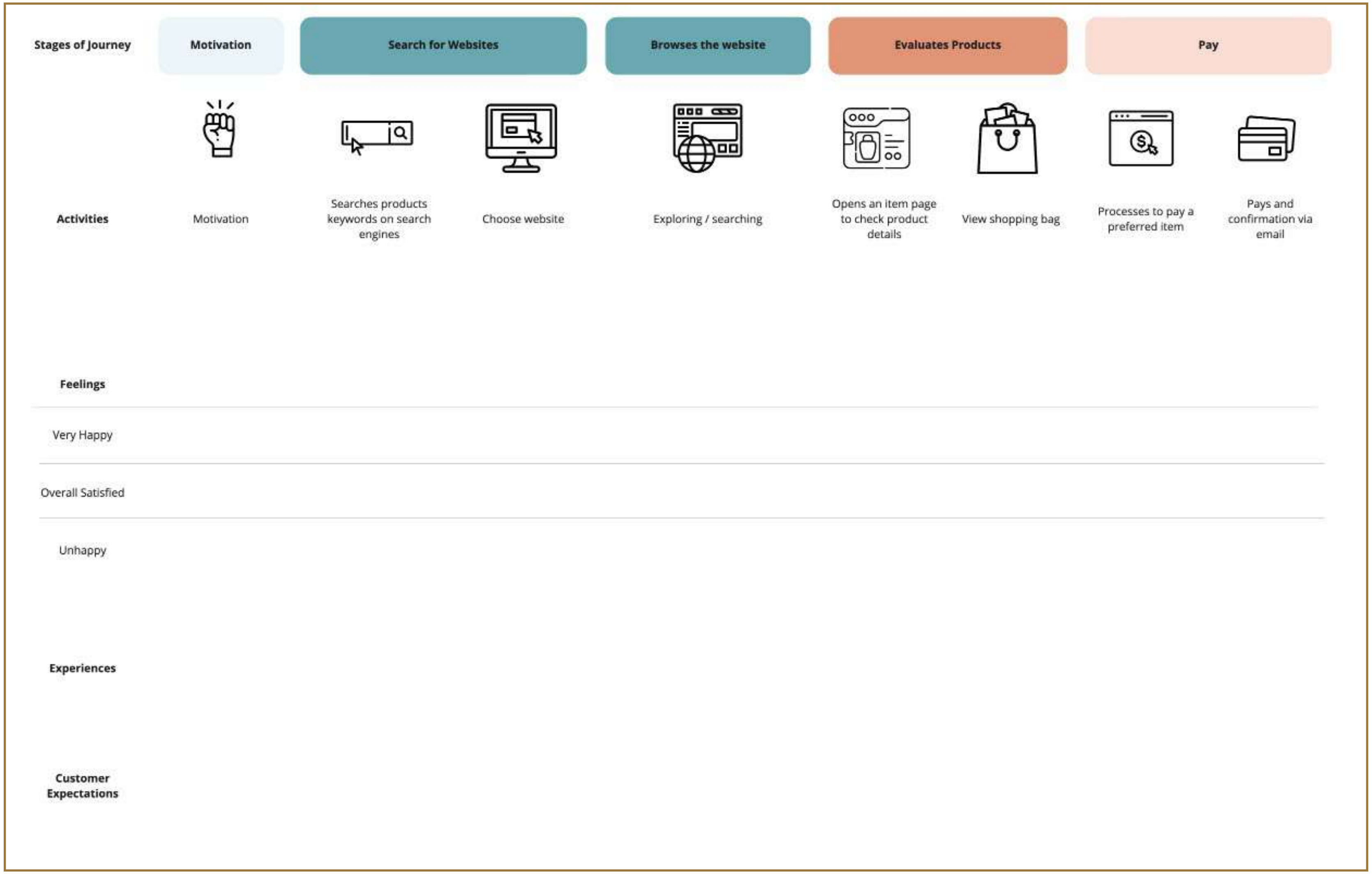


Figure B. Image of the Customer Journey Map based on [1].

C. Shape-change Tools

In addition to the booklet and the customer journey map, quick prototypes have also been made to demonstrate and experience the different shape-change types. This was important to allow the participants to quickly gain knowledge in the field of shape-change and as inspiration for prototyping the tangible personal assistant. In the visualization in Figure C, all quick prototypes are visible with the corresponding shape-change type. The different shape-change types were derived from the paper [6] and were made using various prototyping techniques, such as: 3D printing, knitting, origamic folding etc.

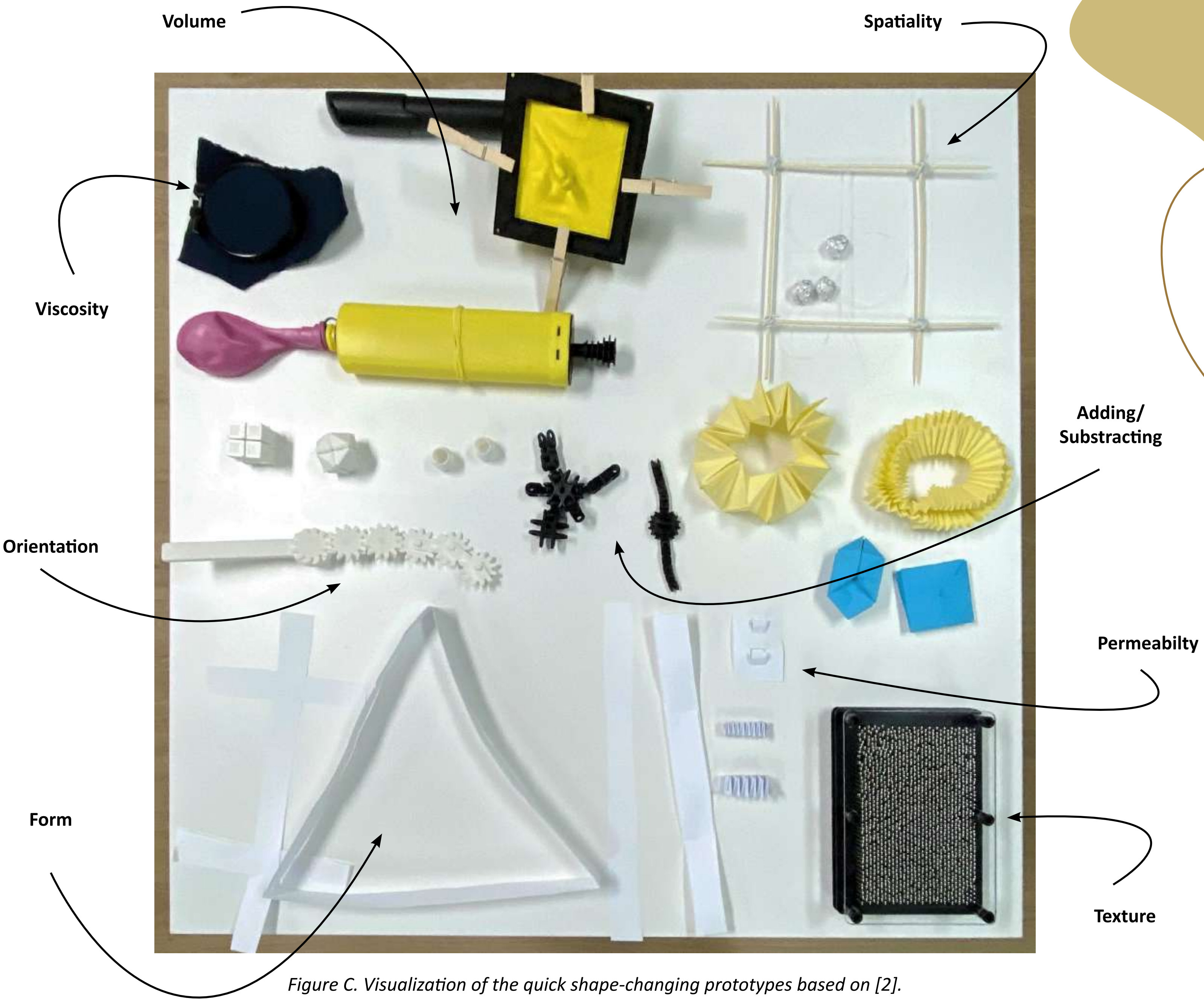


Figure C. Visualization of the quick shape-changing prototypes based on [2].

D. Scenario Cards

Furthermore, scenario cards and interaction cards were made for the co-design session to allow the participants to iterate and look at the prototypes from a different perspective. The scenario cards are ten different cards with ten different items of clothing. There are seven parameters on the cards that can be taken into account when buying the item of clothing, namely: price, material, responsibility, brand, style, color, and pattern. The participants were asked to evaluated whether their concept/prototype would be supportive while looking for the item on the scenario card. The scenario cards are shown in Figure D.

Figure D. The Scenario Cards.

E. Interaction Cards

The interaction cards consist of six different cards inspired by the Interaction Frogger Framework [10]. These are the six different practical characteristics of linking action and information. These aspects are time, location, direction, dynamics, modality, and expression, and when all these aspects come together, the interaction is likely to be intuitive. Ultimately, the participant's goal was to design and think about the interaction with the tangible personal assistant for online shopping. However, the participants were only allowed to take one interaction card, meaning only one of the aspects was reflected on. The interaction cards are shown in Figure E. On the cards, the explanation per aspect is described using the examples of cutting paper with a scissor from the research paper on the Interaction Frogger Framework [10].

Figure E. The Interaction Cards based on Interaction Frogger Framework [4].

F. Result Co-Design Session

In addition to the tools and cards made, after the co-design session an analysis was done on the made prototypes. In the research paper, the most important elements of the prototypes were examined. For this report section, other elements and aspects of the prototype have been evaluated. Figure F illustrates the table with other elements that emerged during the co-design sessions, including the aspects not mentioned in the paper. The two elements are the specific interaction and AI used in the concept.

	Problem	Functions	Type shape change	Interaction	Interaction body	AI	Physical form	Realistic
Pashulp	Difficult to estimate fit	Estimate fit	Volume	(Location) Pull	Body / hand	Product finding / Preferences	Tool	Now
Pauw	Trouble with searching and need for style advice	Searching	Orientation / Form	(Time) Drag / turn	Hand	Product finding / Preferences	Body	Now
Ubofi	Difficult to estimate fit	Estimate fit	Volume / Texture	(Direction) Grab / turn	Hand / finger	Product finding / Preferences	Body/Tool	Texture change / body scan
Fabrizi-use	Do not know how a material feels	Feel materials	Texture / (Viscosity)	(Location) Touch	Finger	Product finding	Integrated	Texture change
Zzzsmorphefi	Not comfortable to shop	Searching	Volume	(Expression) Wrap	Body	Product finding Behavior recognition Product Augmentation	Integrated	Hologram
Blueino	Trouble with searching and need for style advice	Searching	Orientation / Form	(Dynamics) Grab	Hand	Product finding Behavior recognition	Body	Now

Figure F. Table of the results of the Co-Design Sessions.

III. THREE ARTIFACTS

Three artifacts are created to make the three different types of shape-change with function experienceable. This section shows the physical and digital explorations and explains material choices. In addition, the hardware and software of the three artifacts are examined.

A. Explorations

Exploring the three artifacts started by both modeling as well as rendering the designs in Fusion360. This approach was chosen as creating the models allows exploring shapes and materials rapidly. The renders are used to visualize the concepts and are shown in Figures G, H, and I.

Figure G. Renders of the first iteration of the artifact "The Mouse".

Figure H. Renders of the first iteration of the artifact "The Snake".

Figure I. Renders of the first iteration of the artifact "The Peacock".

In addition to the digital explorations, physical explorations have also been done with different materials. The physical explorations per artifact are shown below in Figures G, H, and I. The benefit of physical exploring is that it allows getting a sense of the shape and size, as well as material experience (i.e. texture).

The Mouse

Initially, the idea for “The Mouse” was to process all electronics in an existing working mouse. However, a mouse is built very compactly, leaving no room for new electronics. This was followed by an iteration to tear down an existing computer mouse and remove the electronics so that there is room for new electronics. This meant that the computer mouse no longer functioned as a computer mouse, but the material change could occur. In addition, the size of the turntable for the materials was considered. These will be placed in quarters on the turntable, which is placed on a servo. One of the quarters will then be presentable and thus experienceable each time, and by turning the servo, another quarter is presented. As the mouse required additional electronics (the servo and a microcontroller) to be integrated, as well as needed to function, a third approach was chosen. In this approach, an additional shell is made that is placed over an operational mouse. This allows the original mouse to remain completely functional, while the added electronics can be operational within the space created by the shell.

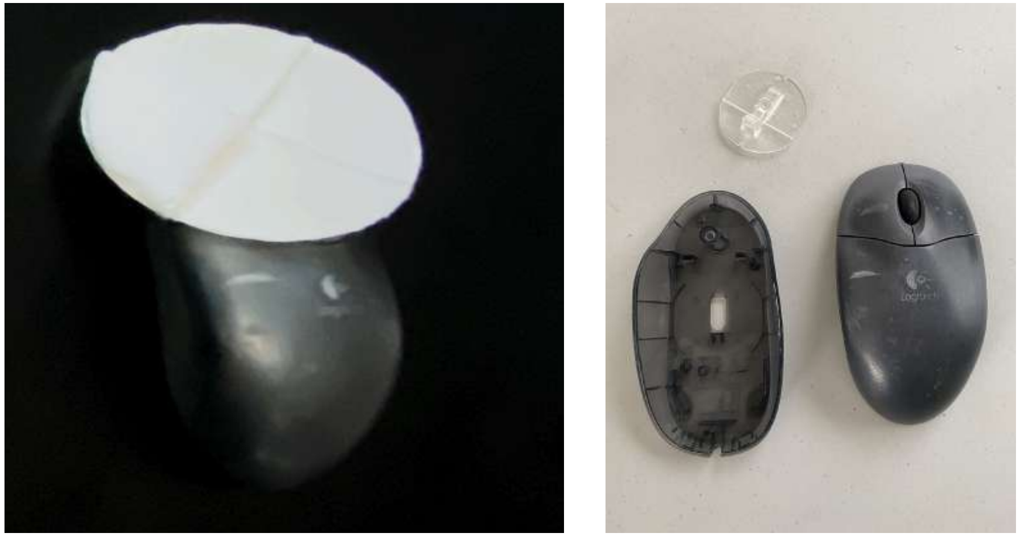


Figure J. On the left is the size of an exploration of a turntable compared to an existing mouse. On the right, an old computer mouse taken apart with the space visible for the electronics.

The Snake

The first iteration of “The Snake” was an elastic band with a hole for a balloon to pass through. For example, this band could be worn around the head or waist, and by inflating the balloon, the band became tighter. In addition, experiments were carried out to explore how the inflatable could be made. To achieve an inflatable shape, the casting of silicone was examined. For this, a mold was made of 3D printed PLA, with a 100% infill, into which the silicone could be poured. First, a first layer was made by pouring the silicone into half of the mold. This dried for a while but not the full curing time. Then a separator made of 3D printed PVA, a filament that dissolves in water, was added. After this, another layer of silicone was poured onto the edge of the mold. Once completely cured, a hole was made in the silicone object in which water could be put so that the separator would dissolve. After the PVA has been dissolved, a tube could be connected through which air can pass to inflate the silicone resulting in a custom inflatable shape. While this approach seemed promising, it was not further explored due to the extensive amount of time required to fabricate a single prototype. Also, the first iteration seemed too fragile to properly demonstrate and test during a design exhibition.

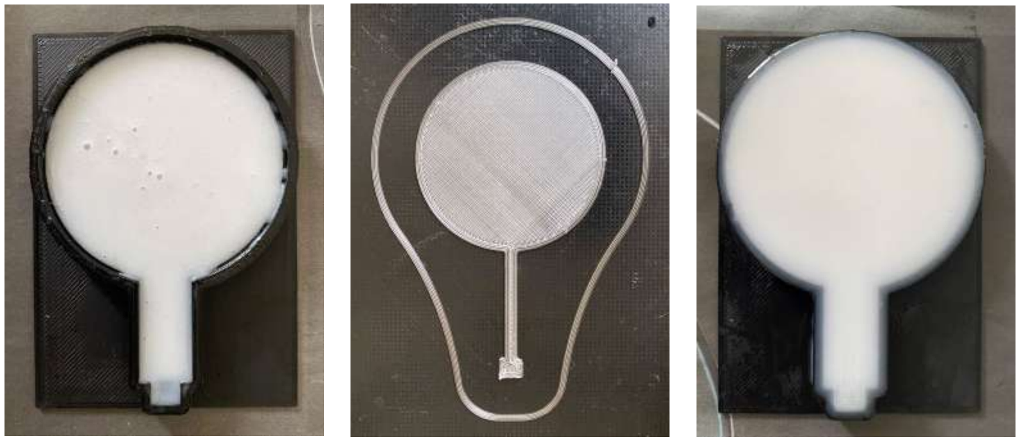


Figure L. On the left the silicone filled to half of the mold. In the middle the separator made of AVS filament. On the right the mold with separator is completely filled.

Figure K. The first physical iteration of the artifact “The Snake”.

The Peacock

For the artifact "The Peacock" several iterations have been made for the origami structures for the fabric. Starting with exploring pieces of foam on fabric to force the fabric to move into the desired shape. Later, 3D printing on fabric was looked at. It was important that the filament melts in the fabric so that the 3D-printed lines remain attached to the fabric, even after folding. The fabric was preferably 100% polyester and not too slippery so that its filament would not slide off. The origami structures are inspired by simple origami hand fans [4] and origami flowers also with the technique of 3D printing onto fabric from conductive origami by Yael Ykirav [3].

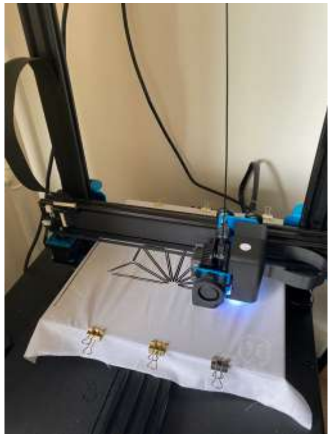


Figure N. 3D printing PLA filament structures on polyester fabric.

Figure M. Foam glued to fabric to test different origami structures for folding the fabric.

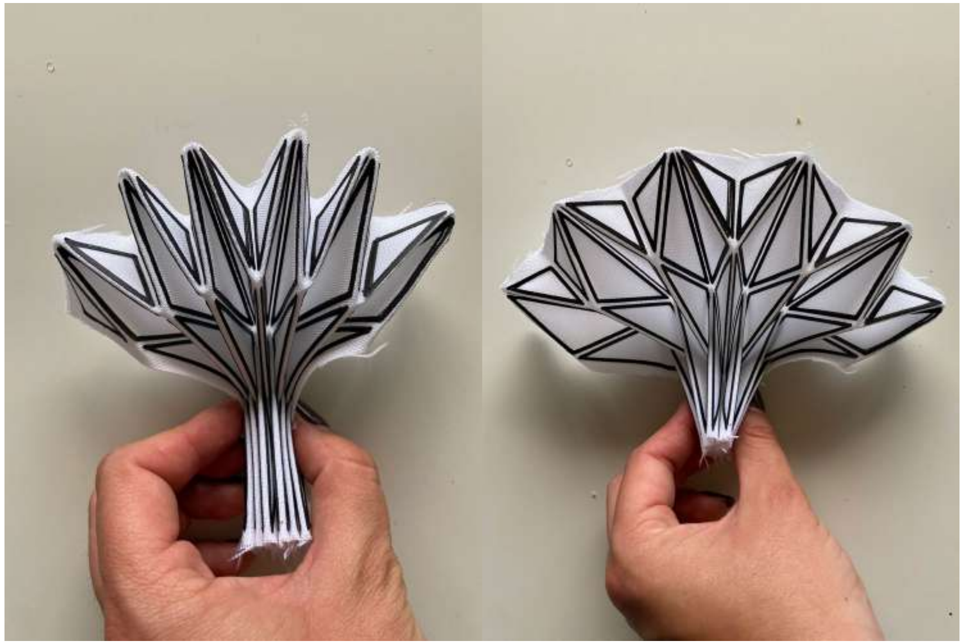


Figure O. An iteration of a half flower structure 3Dprinted on polyester fabric and folded inspired by [3].

B. Material Choices

The three artifacts belong together, which is why a “Form Family” is explored to ensure that the three artifacts also look like they belong together. A “Form Family” can be expressed in several aspects of product design, such as: shape, color, or interaction. In the three artifacts, the form family is mainly reflected through color and textures. In addition, the context has been taken into account, namely the world of shopping for fashion online. Looking at well-known shopping websites or expensive brands, they often look chic, simple, and elegant. Examples are: H&M [5], ZARA [12] or Zalando [11]. There is often one general color representing the company or brand, and the rest is mainly clean white with black. This also had to be reflected in the materials for the three artifacts and the reason why one general color is chosen: the beige. This color is often seen as chic and elegant, especially in combination with black and white. This is reflected in the fabric of the origami fan, the band, and the lower part of the mouse housing. Furthermore, everything is kept beige, black or white except for the bag of “The Snake”, where a soft color has also been chosen that goes well with the beige. As a result, the artifacts will continue to look elegant even when used to shop for clothing items with different colors.

In addition, shopping for clothes is mainly about fabric and that is why different textures of fabrics have been explored. For example, the cylinder of “The Peacock” is entirely soft to create a contrast with the other two artifacts and provoke interaction. The soft fluffiness is something people often want to touch, and where the other two artifacts already have direct interactions, the interactions with “The Peacock” it is stimulated by the soft appearance.

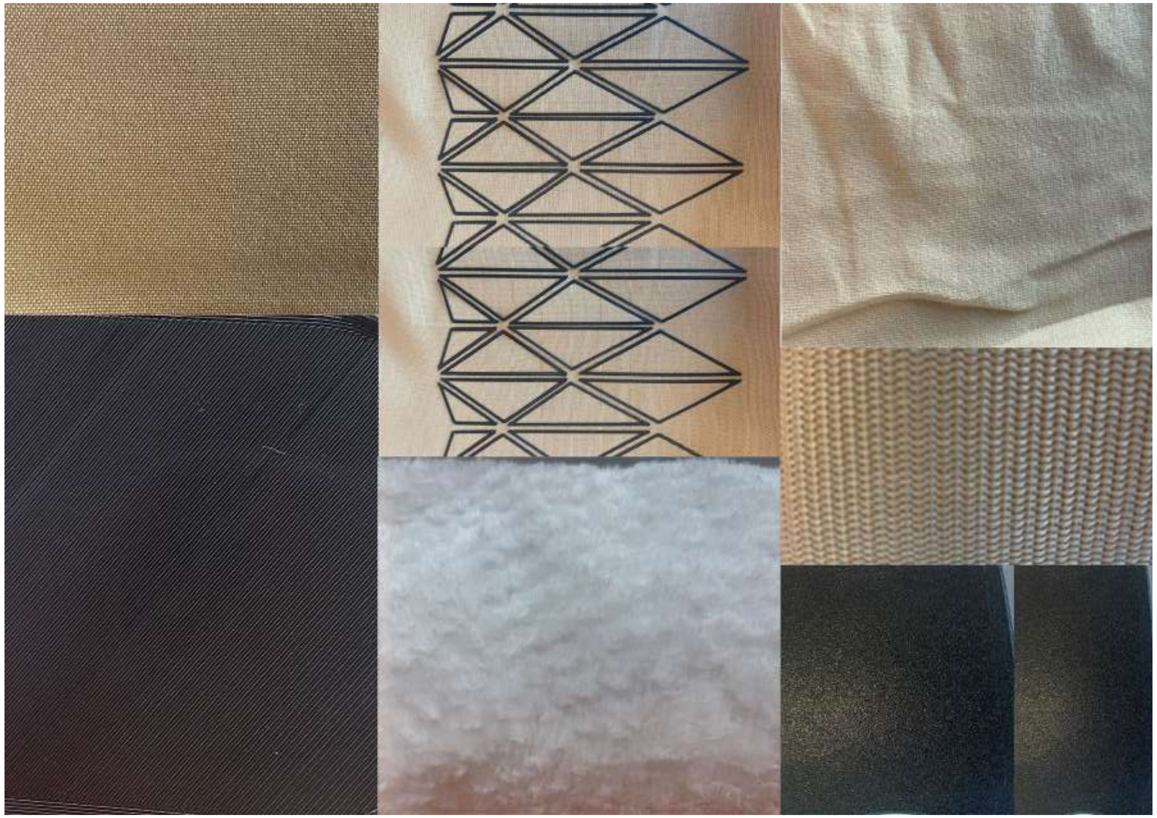


Figure P. Collage divided into three to explore the different materials together.

Figure Q. The final chosen materials together.

C. Hardware

Next to the materials, the different electronic components that are needed to make the artifacts working and experienceable have to be considered in the designs of the artifacts. In the sections below, the different electronic components and the casing designs per artifact are explained and visualized.

The Mouse

The mouse consists of two different parts, the 3D printed cover for the mouse and with a lit, both made of PLA. There is space on the lid to attach the electronics and a hole at the left side by the index finger for the turntable behind it to allow the materials to be experienced with the fingertip. The electronics consist of a micro servo and a Teensy 4.0 [8]. In addition, there is a hole made in the cover for the USB wire of the Teensy and for the wire of the extra power. An extra power supply of 5V, 2A is used to power the micro servo. In addition, a servo attachment has been made for the turn-table. These are also 3Dprinted from PLA on which the 4 quarters of fabric were glued. The 4 fabric sections consisted of three different kinds of materials: latex, cotton, and soft fabric.

Figure R. Images of the artifact "The Mouse".

The Snake

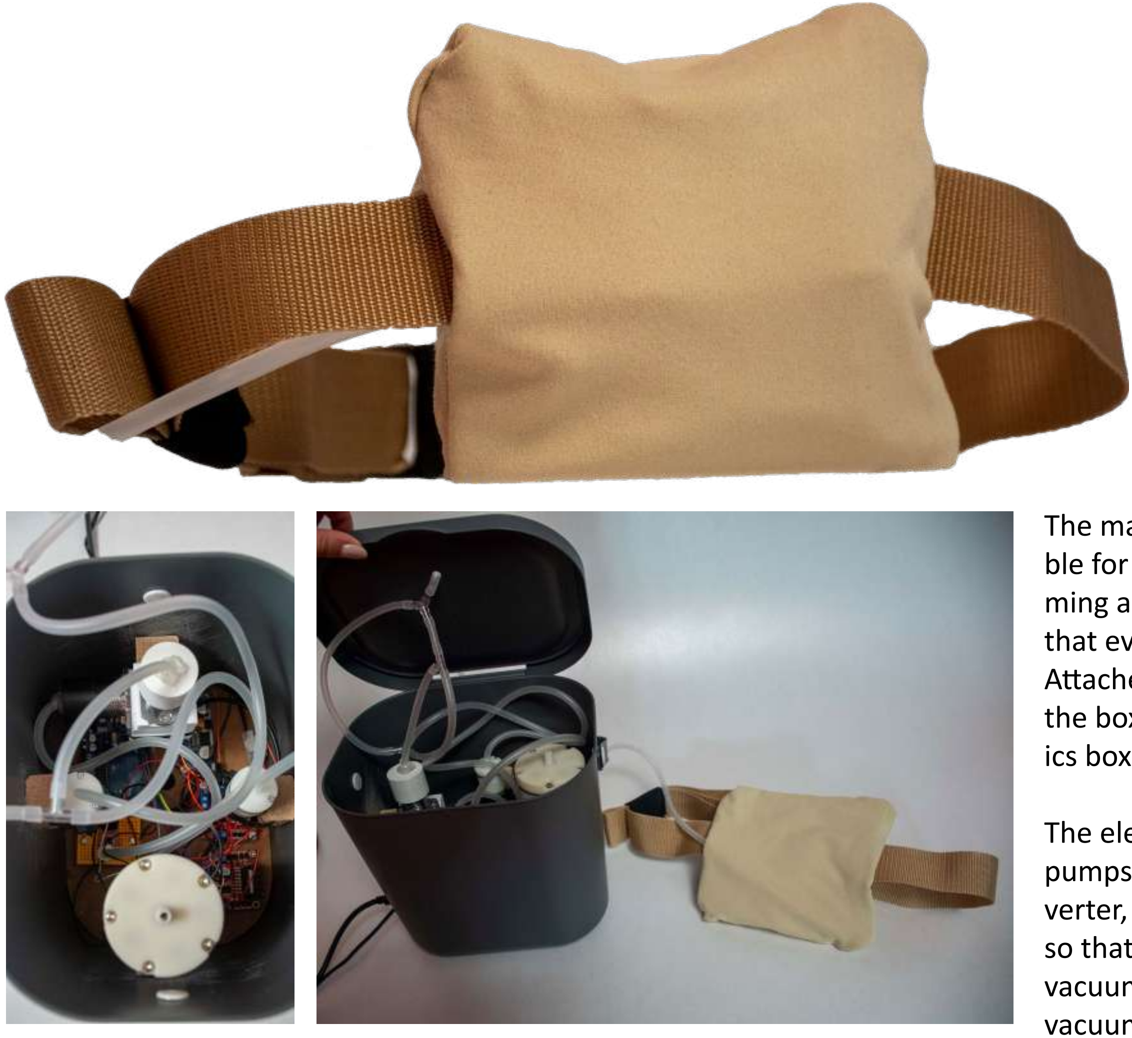


Figure S. Images of the artifact "The Snake".

The main part of "The Snake", the part that is also experienceable and tangible for the user, consists of a band with a bag containing an inflatable swimming arm band. In addition, a buckle has been made that is adjustable so that every user can wear it regardless of the circumference of the abdomen. Attached to the inflatable swimming arm band is a silicone tube that leads to the box with electronics. This tube was kept long enough so that the electronics box could be placed under the table and only the band is visible.

The electronics are housed in one box consisting of an Arduino UNO [2], two pumps, a large vacuum pump, a valve, a pressure sensor, a step-down converter, and two DC-motor controllers. The valve is for keeping the air closed so that at the moment of inflation or inflation, no air can escape through the vacuum valve. The reason for this was that the air could flow through the vacuum pump when disabled. Each motor controller is able to control either 2 valves or pumps. Furthermore, the pressure sensor can measure the pressure in the swimming arm band, in order to know at what level the armband is inflated. In addition, a 9V extra power supply has been used. The power is divided with a step-down converter because the two pumps need 6V and the large vacuum pump 9V. This modules allows the current to be converted to ensure that the 3 pumps and valve get the required voltage through the DC-motor controllers.

The Peacock

The artifact “The Peacock” consists of several parts. Starting with the 3D-printed cylinder of PLA of which the bottom is flattened and on top of that mounts have been made on which the electronics can be attached. The electronics consist of an Arduino UNO [2], two servo motors, and an extra power supply of 5V, 2A. At the back of the cylinder is a hole for the Arduino’s USB cable and the power supply cable. For the servos, two attachments are 3D printed from PLA. These attachements allow the fabric to be clamped into. The fabric is a polyester fabric on which PLA is 3D printedupon in an origami structure. Later it was ironed into the correct shape and the edges of the fabric were made neater by burning them with a lighter. To finish it off, a cover has been sewn from a soft fabric, which goes around the cylinder to complete the design. A press stud is attached to the back to close this cover so that the cables can still pass through.

The servo arms can do different movements at different speeds. In this way, they can slowly move away from each other, causing the fan to open slowly. Furthermore, one servo arm could move and the other one would be stationary. In addition, different rhythms can be programmed to perform different behaviors, such as opening slowly and then closing very quickly and continuously, one after the other. There are many possibilities with this and could be further experimented with.

Figure T. Images of the artifact “The Peacock”.

The Software

A Processing [9] interface has been made for experiencing the artifacts. An image has been created that resembles a laptop screen where an online shopping website has been recreated. On this website, you can see four different pictures with four different pants, all with different prices and materials, but the same size. However, because they are from different brands, the size is not exactly the same. Planes were created in front of the images and made transparent, and by hovering with your mouse over these planes a signal is sent to the Arduino over Serial communication. This is the same for every artifact so that it knows when hovering over a certain image to which mode it should go. In addition, a control interface has been made for the main interface to be able to switch between artifacts. This was important so that it was easy to switch between artifacts during the demo. In addition, three more buttons have been added to this control interface to inflate, deflate, and disable the pumps of the artifact “The Snake”. The reason for this is because the main interface “The Snake” slowly blew up because it had to measure the value of the pressure gauge every time to know if it was already at the correct position. In the current setup, the measurement took quite some time to be performed. As the motors are required to be idle to perform the measurement, the inflation process to change large amounts of air took too long.

In addition, the four fashion photos that had to be made for the website interface for the demo were also thoroughly considered. These were made in a photo studio where everything was the same color, the background and objects, so that that color could easily be changed to the color needed for the style of the interface. Black has been chosen to emphasize the color of materials in the photos and the layout has been left simple white, comparable to well-known fashion shopping websites [5, 11, 12].

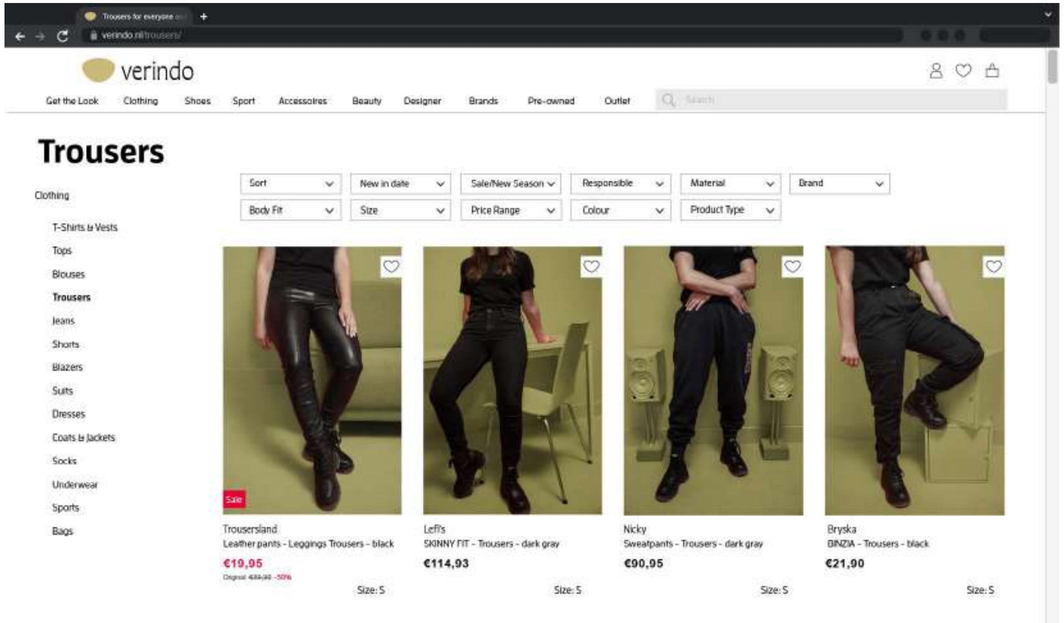


Figure U. The Processing Interface

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