ShapeShare: A Conceptual Toolkit Based on a Modular Shape-Changing Interface for Supporting Remote Co-Design

ANONYMIZED FOR REVIEW

Remote collaboration is a challenge for physical product designers, and especially limits the mutual communication of the 'thinking through prototyping' approach. Inspired by the NURBSforms and self-shape sensing technologies, we proposed ShapeShare, a conceptual toolkit for supporting designers to build a design and share it physically with remote collaborators. By using stop-motion videos and low-fi prototypes as probes, the concept were evaluated through questionnaires and workshops with a simplified version of the toolkit. The result shows the potential to bridge the gap between digital and physical, especially in the exploration phase of remote co-design.

Additional Key Words and Phrases: Design collaboration, Remote prototyping, Shape-changing, Shape memory alloys

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1 INTRODUCTION

The world becomes increasingly connected, therefore collaborative work becomes more distributed to multiple locations. Current restrictions regarding the COVID-19 pandemic are strongly driving this trend, making remote digital communication and collaboration the single possibility in many cases. A large amount of commercial solutions are available providing video communication and sharing digital content [1] [2]. However in many cases collaborative work revolves around mutual understanding of physical objects, especially in the field of design. Working with physical prototypes has been proven to be effective to describe, explore and iterate on design solutions because physicality supports the expression of design aspects like form, scale and spatial proportions better than their digital agents [3] [5]. Moreover, the direct hands-on interaction with physical prototypes supports exploration, which enhances creativity and awareness of the context [14] [7]. Designers tend to use a 'Thinking through prototyping' approach, using physical tools in the design process such as sketches, low-fidelity prototypes and models [9]. This approach is part of a greater methodology for designers to think through doing [7]. Klemmer et al. [7] identify the practice of the manipulation of artifacts to better understand a task's context as an important aspect of 'thinking through prototyping'. Considering remote digital collaboration, this approach is limited. How the exchange of prototyping experiences between collaborators can be replicated for remote and distant collaborations, is yet to be designed for [6].

[1]https://www.microsoft.com/nl-nl/microsoft-teams/group-chat-software
[2]https://zoom.us/

Inspired by the work on shape-changing interfaces, physical design explorations and modular programmable surfaces, the goal of our work is to enable shared physical exploration of form, scale and spatial proportions in remote design collaborations. By focusing on the assembly of modular curvature manipulation using shape memory alloys we aim to allow for remote exploration of physical form by a 'Thinking through prototyping' method. By uploading the actuators positions supported with photos for assembly, explorations can be sent digitally to remote collaborators to create a mutual understanding of the physical form through actuated surfaces.

In this paper, we envision the integration of of NURBSforms [17], modular constructive assembly of strip actuators, and the existed self-shape sensing technologies [1, 15] as the means to establish a mutually understandable prototype in remote collaboration. NURBSforms are effective in variable curve modeling through a modular shape-changing interface. Based on the capability of NURBSforms, we introduce a conceptual toolkit, ShapeShare, which allows for designers to support physical prototyping for remote design collaboration. We envision ShapeShare embodies the work of NURBSforms on actuated modular surfaces to control curvature remotely. With this toolkit, designers can assemble individually controllable strips to create shapes. Assembled shapes can be shared with collaborators by mimicking the assembly of the shape, subsequently actuating curvature of the individual strips after. With this approach, designers benefit from shared physical understanding and exploration in remote design collaborations.

By using stop-motion videos and low-fi prototypes as probes, the concept were evaluated through questionnaires and workshops with a simplified version of the toolkit and elicit design implications for further iterations of service designs or the realization with the NURBSforms Technology.

The main contributions of the study is the preliminary findings that we obtained from the study, which provides understandings on how a shape sharing system could enrich the physical prototyping experience in remote design collaborations, improve mutual understanding of physical form, scale and proportions, and expand the NURBSforms technology's use cases and application scenarios.

2 RELATED WORK

2.1 Remote collaboration

Developing technologies and tools to support remote design collaboration, addressing the challenge of communication-based on locally-present physical objects has been long researched [10]. While virtual alternatives such as a head-mounted camera to share a first-person viewpoint can act as the basis for communication, this approach requires participants to translate local experiences into a representative abstraction for themselves [10].

Many software and platforms support remote collaboration in sketching and modeling, such as Miro [3], Solidworks [4] and Fusion360 [5]. However, users still lack physical experiences that inspire themselves and others. Next to that, sketching is less intuitive to create or understand than 3D objects, whereas modeling costs time and the scale is hard to perceive.

Some researchers are exploring AR technology to support remote physical design [8]. It provides a more intuitive experience of "thinking through prototyping" for designers. Nevertheless, the limitation of Hololens's field of view makes the work area very small, and the analysis of hand movements requires very complex algorithms. In terms of experience, the lack of tactile sensation makes it difficult for the remote colleagues to perceive the form and scale of the design.

[3]https://miro.com/
[4]https://www.solidworks.com/zh-hans/category/collaboration
[5]https://www.autodesk.com/products/fusion-360/blog/how-to-use-fusion-team-to-collaborate-on-projects-with-anyone-anywhere/

2.2 Shape-change using shape memory alloys

In the last decade, there is a growing amount of research contributions in the field of shape-changing interfaces. The notion of shape-change is strongly influenced by the vision of Radical atoms [4]; "giving dynamic physical form to digital information and computation". Research efforts in this field use tangible modeling tools combined with actuation, enabling the design to change shape according to digital and/or physical user input. Influential contributions have used swarm robots for an interactive user interface [16], thermoforming for interactive fabrication techniques [11], linear actuators to create displays [2], and pneumatic technology for shape control [19]. However a more cost-efficient approach to actuating surfaces is the use of shape memory alloys (SMA). SMA wires are valuable for their reversibility of shape-change, speed of use, quiet operation, reduced size and weight and their ability to react to external stimuli [13].

2.3 Modular Programmable surfaces

Shape memory alloys are used in several research prototypes to program the actuation of surfaces. Prototypes embed these alloys in materials, like Smaad [18], weaving the shape-memory alloys in fabric surfaces. This surface is modular in rectangular and triangular shapes, allowing to build actuated designs. However edges of these shapes cannot be individually controlled. Bosu [12] implements shape-memory modules in different geometries to quickly assemble actuated surfaces. This approach enables bi-directional shape-change however the geometries are controlled together, limiting the ability for individual control. Moreover, this research prototype is limited to on/off states and unable to set variable curvatures. A recent study, NURBSforms [17], applies bi-directional shape input, individually modular and variable controlled surfaces. This approach can provide designers with more flexibility in assembly, enhancing the exploration of curved surfaces during physical prototyping. Moreover, the characteristics of reversibility and repeatability in transformation of the individual modules make the application suitable for a wider range of use cases. The use of standard hardware components make it accessible to implement in commercial applications.

3 SHAPESHARE: A CONCEPTUAL SHAPE-SHARING TOOLKIT

We propose ShapeShare, a conceptual toolkit that enables designers to share physical explorations of form, scale, and spatial proportions in remote design collaborations. The toolkit consists of several shape memory strips of different lengths and covers of different shapes and materials, see Figure 1. The form factors of the strips are built based on the dimensionality, capability and limitations of the existing technologies of NURBSforms [17]. Furthermore, we considered the self-shape sensing features that has been demonstrated in FlexiBend [1] and ShArc [15] to be integrated into the each strips. Together we illustrate the use case and the workflow according to the capability and limitations of the described in NURBSforms.

3.1 Step 1: Create a shape

A shape can be physically prototyped with the ShapeShare toolkit, by connecting and actuating the strip modules. The strips and covers can be connected easily with the small magnet on the end of each module. Combining strips and covers enables a diverse range of possible structures in model making, as can be seen in Figure 2. The shape memory strips can be controlled individually with the microchip on them. To physically create a shape, users input through gestures, that is, moving a magnet closer or further away for hall-effect sensor input (Figure 2). With the pre-trained shape memory alloy embedded, the strips can be thermally-actuated by the circuit and lead to different extents of C-shapes. As a result, several strips support the cover to display various curved surfaces representing design ideas.

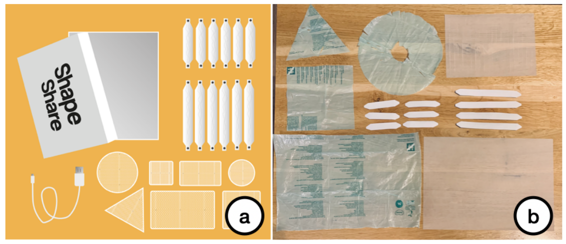

Fig. 1. Two versions of the toolkit (a) in the conceptual toolkit, with shape memory alloy and electronic components embedded, (b) the simple and non-electronic toolkit for user evaluation.

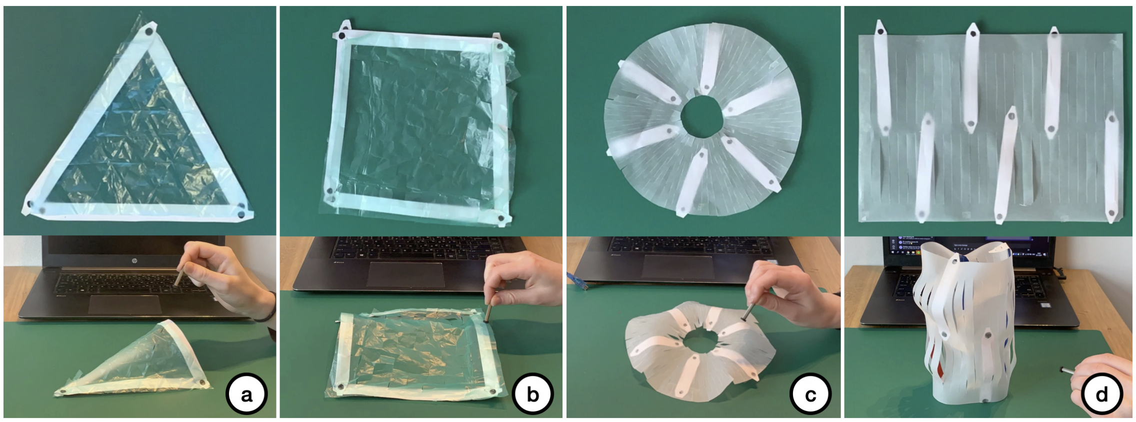

Fig. 2. Creating various shapes with different combinations of elements in the toolkit, and input with gesture. (a) a triangle shape, (b) a square shape, (c) a disc shape, (d) a cylinder shape.

3.2 Step 2: Share a shape

As the shape is created, the user can connect the strips to the computer for sharing, see Figure 3. The electricity of circuits is recorded in the microchip when the user is prototyping, which enables digitalization and duplication of the shape. For sharing the shape, the user should also attach a picture of how they connect the strips and covers to the link generated by the system, so the elements could be connected by the remote collaborator and the shape will be actuated in the same way.

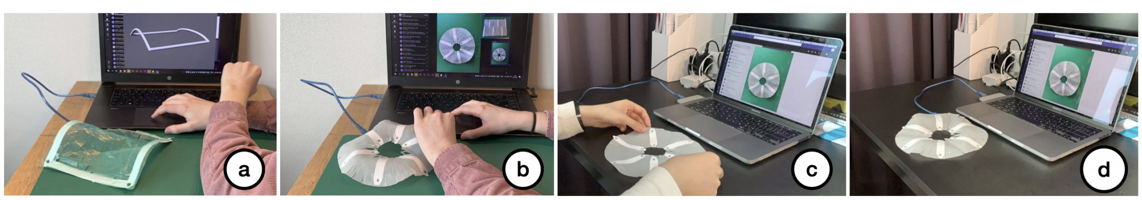

Fig. 3. (a) Digitalizing the created shape, (b) share the link and a picture, (c) the remote collaborator connects the elements in the same way, (d) the shape is actuated by the software.

4 EVALUATION

The potential and usability of ShapeShare was evaluated using 1) an online questionnaire and 2) an online workshop evaluation, both aimed at gaining quantitative and qualitative results.

4.1 Online Questionnaire

4.1.1 Participants and Methods. An online questionnaire was distributed and filled in by 20 Industrial Design students of which 12 had prior experience with remote design collaboration. In the first section of the questionnaire, we asked participants about their previous experiences with remote design collaboration. This way we got more insight into methods used and existing struggles when prototyping remote. In the second section, we introduced the video clips created to communicate the concept of ShapeShare. It was asked whether these videos were clear and communicated the concept well, to rule out any misunderstandings or confusion among the participants. In the third and last section, participants were asked for their insights and thoughts on the concept, what application possibilities they saw and how this tool might affect the remote design process.

4.1.2 Results. In the first part of the questionnaires, 7 out of 12 participants who had previous experience of remotely physical design claimed the difficulty of communication and mutual understanding. Though they were supported by sketching, mood boards, and 3d modeling tools, they felt hard to describe the shapes and interactions of their concepts. The conceptual video clips were perceived as clear and reached average scores of 3.55, 3.6, and 3.95 (scaled 1 to 5). So we improved the video clips and combined them in the workshops. The results of part three showed the concept makes communicating design ideas more tangible, which reduces vagueness, especially when the other designer can duplicate the same shape easily. It also helps to quickly adjust the prototype or to explore more options, and reduces the time spent on a 3d model or verbally explaining. However, some of the participants were concerned the application is still limited to general shapes.

4.2 Online Design Workshop

4.2.1 Participants and Procedures. 2 online workshops were hosted, each containing 3 Industrial Design students with prior remote design collaboration experience. The goal of these workshops was to gain more insight into the usability of the tool and to validate the use of the tool idea conversion. All participants were provided with the simplified toolkit, containing 10 strip modules, 4 defined covers and 2 undefined covers, see Figure **??**(b). With the use of a semi-structured interview, an open discussion took place addressing the participants' experiences and pitfalls with remote design collaboration. Next they were asked to explore the provided toolkit and see which shapes they could create. The participants were then given time to create a design or product with the toolkit after which they explained what they had created and how they approached the prototyping with the toolkit. To end the workshop, the participants reflected on the usability, applications, and limitations of the toolkit together.

4.2.2 Results. We discuss the results in three parts: comparing previous experiences, prototyping with the toolkit, explaining the design, and reflection.

Comparing with previous experiences. In both sessions participants mostly described using basic material readily available at home, like pen and paper, to communicate exploration and design ideas by showing the object to a webcam and providing auditorial descriptions. To circumvent this method some participants divided the tasks in the design process, making either one person responsible for prototyping or do it all individually. Other approaches described used 3D printed models to share through a webcam including descriptions or recording the model making process and sharing the video with their collaborators. Comparing their online collaboration experience to their offline experience, participants emphasized that online it was harder to develop understanding of the colors and size. In this form of collaboration, they point out that it costs more time to describe the physical prototypes to each other and that they can only see the prototype, unable to point out specific parts or interactions. One participant said; "Online you can't experience each other's prototype so you are less critical of it", indicating a reduction in design critics due to a lack of experiencability. Also, not being able to work together on a single prototype, and having access to the same materials is mentioned as an obstacle: "In online prototyping I miss being able to work with multiple people on the same prototype and also all having access to the same materials instead of only videos or pictures"

Prototyping with the toolkit. Observing the participants exploring and modelling a product prototype, participants combined multiple sheet materials and strips to generate shapes. During this process it could be seen that they observed the design result throughout the process to reflect on the outcome, developing the prototype iteratively. This gave insight into how the toolkit influenced the design thinking of the participants. Developing the models, the participants mostly used the sheet material as a basis of the forms, whereas the strips most often served the purpose to model design details in the overall shape and act as material to support the structure. During the observations two participants used tape as a support material to hold the form of the prototype.

Explaining the design. The outcome of product ideas is shown in Figure 4. Three out of the six shapes (b,d,e) were built out of two or more separate elements using the rectangular, round and triangular shapes. It was remarkable that two participants from different design sessions came to the same shape, described as the 'abstract mushroom'. The participants emphasized that the toolkit was good to explore and make organic shapes. Explaining the design prototypes, a participant pointed out that she felt constrained designing with the toolkit: "I got inspired by the pictures you showed and I based the shape on what the materials allowed. Not all ideas I had I could build.". Moreover, rather than the static products as we exemplified in the conceptual video, the participants explored the products to be more interactive (a,b,c), such as shape-changing for notification, or interactive lighting.

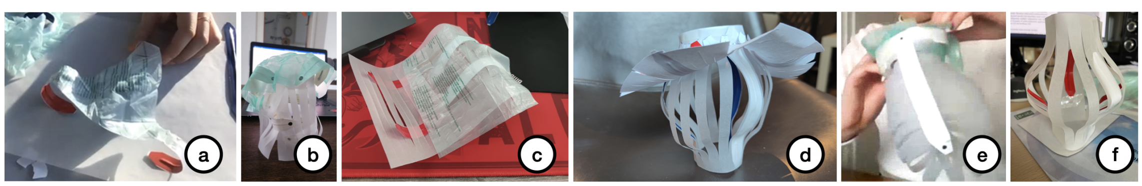

Fig. 4. The product ideas generated in the workshops:(a) Deformable thermometer (b) Deformable mushroom for notification (c) Wireless charging mobile phone/pad holder (d) Mooncake box that can be turned into lantern (e) Round-base vase with lid (f) Lantern.

Reflection. Through a semi-structured interview, participants were asked to share their experience regarding the implementation of the toolkit. Participants in general emphasized that this approach has strong potential to bridge the gap of physical prototyping between collaborators. A participant described it as:"A good way to avoid misconceptions of physical form in the design process". In this design process, the value of the tool was mainly recognized for quickly exploring different forms, especially more organic and fluent forms which is time-consuming when using digital modeling. Therefore five out of six participants said they would use the toolkit as envisioned when it would be readily available for all the collaborators. However, as the tool was valued for iteratively exploring form in the beginning of the design process, the participants did not feel confident to use the tool for creating prototypes with any form of detail, or of higher complexity. Next to that, half of the participants felt constrained in expressing their product ideas through the tool, mainly because they felt that the toolkit did not provide enough strip modules in quantity and different sizes. In addition, even though we provided pieces of sheet material that the participants could freely cut and shape, all the participants only used the already shaped ones. Nevertheless, two participants felt biased in the process of form exploration by the provided forms of sheet materials. A participant emphasized: "The surface is also really important. The paper offered was flexible, but how you cut it limited the options to design". Regarding materials, a participant pointed out that providing multiple materials with different characteristics might significantly improve the quality of the build prototypes.

5 DISCUSSION

This study has generated various interesting insights for the use of ShapeShare to aid remote design collaborations in the exploratory phase. However, to fully develop a suitable toolkit tailored to the scenario of remote design collaboration, further research and development will be needed. Several considerations are presented for future work to overcome the limitations of our study.

5.1 Toolbox' contents

As addressed in the evaluation of the user studies, the participants felt somewhat limited in the designs that could be created with the provided amount of strip modules, covers and materials in the toolkit.

The toolkit contained 2 different cover materials. Even though the materials varied in flexibility and texture, this was not sufficient to express different product properties and tangible experiences. Also the patterns, which were cut into the materials to provide shape change, steered the participants into certain directions, whilst that is something that should be avoided. More research and experimentations should take place to find cover materials that allow for shape change and can mimic the experience of different tangible prototypes.

The participants were provided with 10 strip modules, 4 longer and 6 shorter ones. During the reflection, they reported this to be too little to design more complex shapes or designs consisting of multiple structures. Therefore, the quantities and qualities of the materials offered should be further evaluated to reach a balance where the user is able to express their ideas in physical form, but does not overwhelm the remote collaborator in reconstructing the same basic structure for the shared product.

There are some technical implications to scaling up the amount of strip modules provided. Each individual strip module has to be connected either to another module via the magnet, or wired to the Arduino controlling the structure. With the upscaling of the modules, these amounts of connections become harder to realize and support. An interesting future step to resolve this issue would be wireless shape actuation, but this is yet to be researched.

5.2 Complexity of Designs

Design ideas can range from simple two-dimensional shapes to complex and large structures. This is something we encountered when asking the participants to think of a product and trying to recreate it using ShapeShare. The participants did not feel confident creating complex shapes containing details and interaction with the toolkit, and some participants felt constrained in expressing their product ideas through the tool, mainly because they felt that the toolkit did not provide enough stripmodules in quantity and different sizes.

Because of this limitation, the toolkit was defined to be more useful in the exploration phase of a design process, where the focus lies on idea generation and shape definition instead of details and interaction. If we would aim for the toolkit to be usable later on in the design process as well, more modules, material and refined shape changing should be realized within the toolkit and technology. Another possibility would be to enable digital rendering of the shape created which would allow for digital tweaking and adding of details. This render could then be used alongside the physical prototype to strengthen the concept and provide more information.

5.3 Real-Time Shape Sharing

As of now, the ShapeShare tool is not able to change shape in real-time with one user creating a shape and a remote collaborator receiving the shape. The user will have to re-upload a shape if changes have been made to the curvatures of the strip modules. Even though this process does not take a long time, real time shape change would be an interesting upgrade of the tool that would allow for smoother communication and exchange of ideas. Since the technical feasibility of real time shape change of the SMA is outside our scope and skillset, we would opt to collaborate with the creators of the NURBSforms to realize this.

6 CONCLUSION

We presented ShapeShare, a conceptual toolkit supporting physical exploration in remote design collaborations. Inspired by the work of NURBSforms and self-shape sensing technologies, a toolkit consisting of modular actuator strips and surface material is provided to build prototypes that can be shared through physical actuation to remote collaborators. By using stop-motion videos and low-fi prototypes as probes, we create experiences that embodied the use of this tool and provided designers with enhanced understanding of form, scale and spatial proportions in collaboration surpassing the limitation of thinking through prototyping in video aided remote collaboration. The feedback and experience that we obtained through a questionnaire and design workshop show how such a toolkit can be particularly interesting for the exploration of form in the earlier stages of a co-design process, potentially bridging the gap between physical and digital prototyping. Overall, the participants were satified with the experiences, but they also felt limited by the amount of material and influenced by the cutouts of the sheet material provided in the toolbox. Future work will have to focus on finding a balance between the amount and form of materials provided, material costs and technical limitations considering a growing amount of actuated strips. Future work can further investigate how such an experience could enrich the physical prototyping experience in remote design collaborations, improve mutual understanding of physical form, scale and proportions, and expand the NURBSforms technology's use cases and application scenarios.

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