Lifting Kirigami Actuators Up Where They Belong:
Possibilities for SCI

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ABSTRACT

Kirigami Actuators are two-dimensional patterns that allow the translation of a simple actuation in one dimension into a complex transformation in another. Kirigami Actuators represent one metamaterial strategy that designers of Shape-changing Interfaces could utilize to minimize the size and complexity costs of actuation. Metamaterials yield great promise for HCI and Shape-changing Interfaces in particular. In an effort to reveal the promise of Kirigami Actuators for the design of Shape-changing Interfaces, this pictorial presents several design tactics for a specific Kirigami Actuator: The Lift pattern. These tactices outline how different components of the pattern can be changed to strategically alter the transformational qualities of the pattern. Initial concept sketches are presented as inspiration for future work.

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Authors Keywords

Kirigami Actuators; Metamaterials; Shape-Changing Interfaces

CCS Concepts

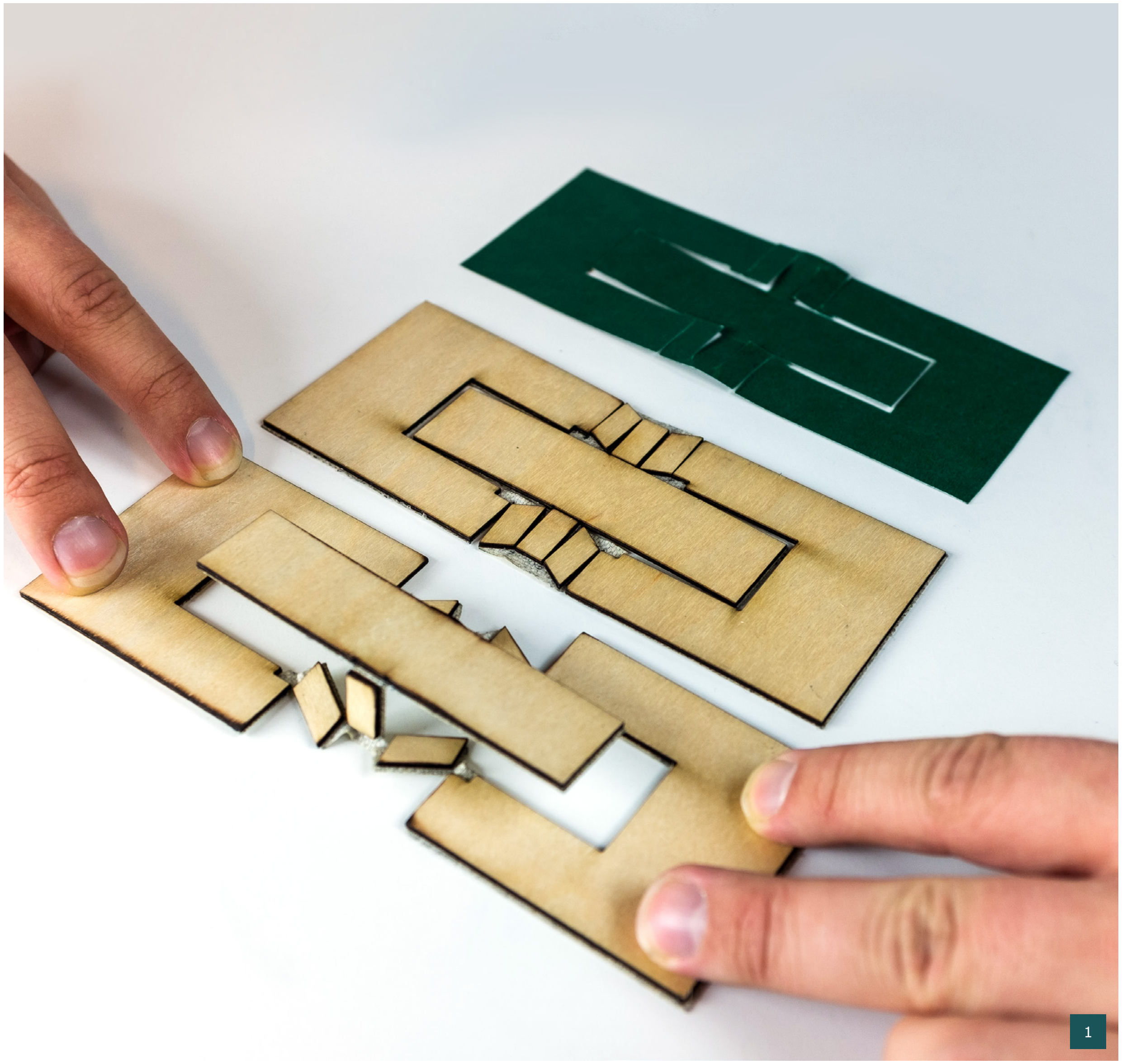
• **Human-centered computing~Interface design prototyping** • Human-centered computing~Systems and tools for interaction design • Hardware~Sensors and actuators

INTRODUCTION

One of the basic challenges when designing shape-changing interfaces is, that as the need for complex yet controlled movement increases, so does the complexity, size and amount of actuators needed. One way of addressing this challenge is by using mechanical meta-materials [15]. Created by engineering the mechanical properties of their material structure, meta-materials can provide new possibilities for Shape-changing Interfaces (SCI) by for example minimizing the need for actuators.

Research has already produced several examples of shape-changing interfaces that use mechanical metamaterials within HCI [2,4,5,9,10]. The potential for SCI to seek inspiration in both Material Science and Engineering, has been illustrated by Qamar et al. [15], showing for example how auxetic materials [9,10], and foldable structures using origami and kirigami principles [13,12] could provide new ways of actuating shape-changing interfaces.

The work presented in this pictorial utilises a metamaterial principle called Kirigami Actuators, presented by Dias et al. [7]. Kirigami Actuators take advantage of thin elastic sheets’ ability to easily bend, by cutting such sheets into different patterns. These patterns are designed such that a translation of the pattern in one dimension leads to complex transformations in other dimensions. The Kirigami Actuators are shown



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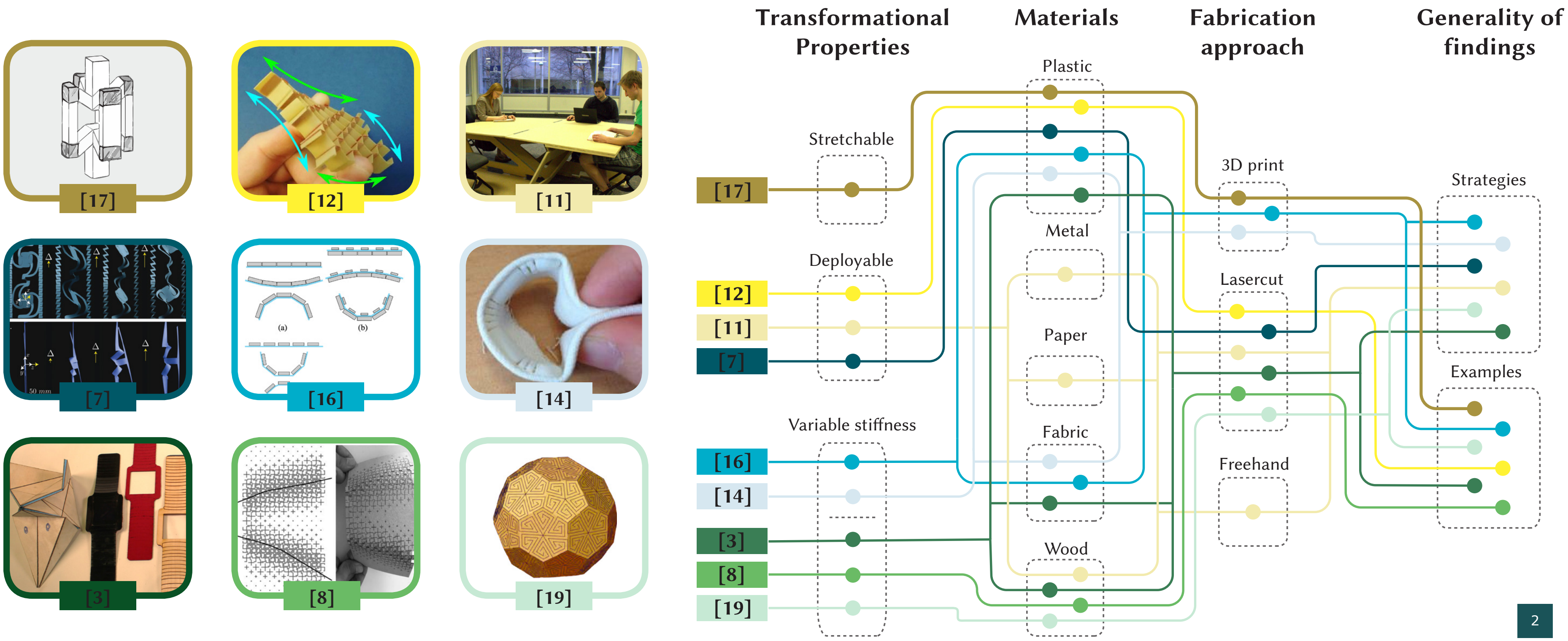
by Dias et. al. to work from nano- to paper-scale thickness and proven to be scale-invariant in theory. Kirigami Actuators will however not work in just any material, since they rely on the bending qualities of thin elastic sheets.

This pictorial addresses the challenge of how the original Kirigami Actuators can be adapted into a ressource for designers of Shape-changing Interfaces. This challenge is two-fold. First, the usefulness of thin mylar sheets as actuators in Shape-changing Interfaces is, arguably, quite limited. The question is; in what materials can Kirigami Actuators be realised, that are robust enough for users to interact with, and allow designers to alter their aesthetic qualities? Second, an exploration of how the transformational qualities of the Kirigami Actuators can be altered is needed.

The pictorial addresses this challenge by exploring the possibilities for altering the Lift pattern, as seen in figure 1; a Kirigami Actuator, where a simple translation of the sides lifts up the central component of the actuator. Different material combinations and fabrication techniques are explored, that allow Kirigami Actuators to maintain their transformative qualities. Furthermore, experiments exploring the effects of altering different components of the Lift pattern, are presented.

The pictorial contributes to the SCI field, through a set of initial tactics informing the use of Kirigami Actuators when designing Shape-changing interfaces. The tactics illustrate how certain changes to the cutting patterns control the stability, amplitude and directionality of the transformation, how to prevent interlocking, as well as the degree of freedom to design the visual appearance. Finally, reflections on bridging SCI and Engineering and Metamaterials are presented, along with an initial set of concept sketches as inspiration for future work.



RELATED WORK

This figure (2) presents a visual mapping of the related work, illustrating nine related examples of work situated in the intersection between material science and HCI. The related work mapping identifies common concepts and themes, such as transformational properties, materials and fabrication approaches, and the generality of the findings. The categories employed to group the transformational properties are inspired by Qamar et. al.’s [15] review of morphing materials for the design of shape-changing interfaces. The nine examples are grouped into three overarching categories; stretchable structures (e.g. [17]), deployable structures (e.g. [7,12]) and variable stiffness (e.g. [3,8,14]). The examples utilize both single materials (e.g. [8,12]), or combinations of materials (e.g.[3,11]), which are fabricated in different ways, either 3d printed (e.g.[17]), laser cut (e.g.[19]) or freehand (e.g.[11]).

Lastly, the mapping illustrates the contribution of the work, whether the examples are allowed to represent the approach in themselves (e.g.[17]), or if the work is summarized into strategies (e.g.[7]).

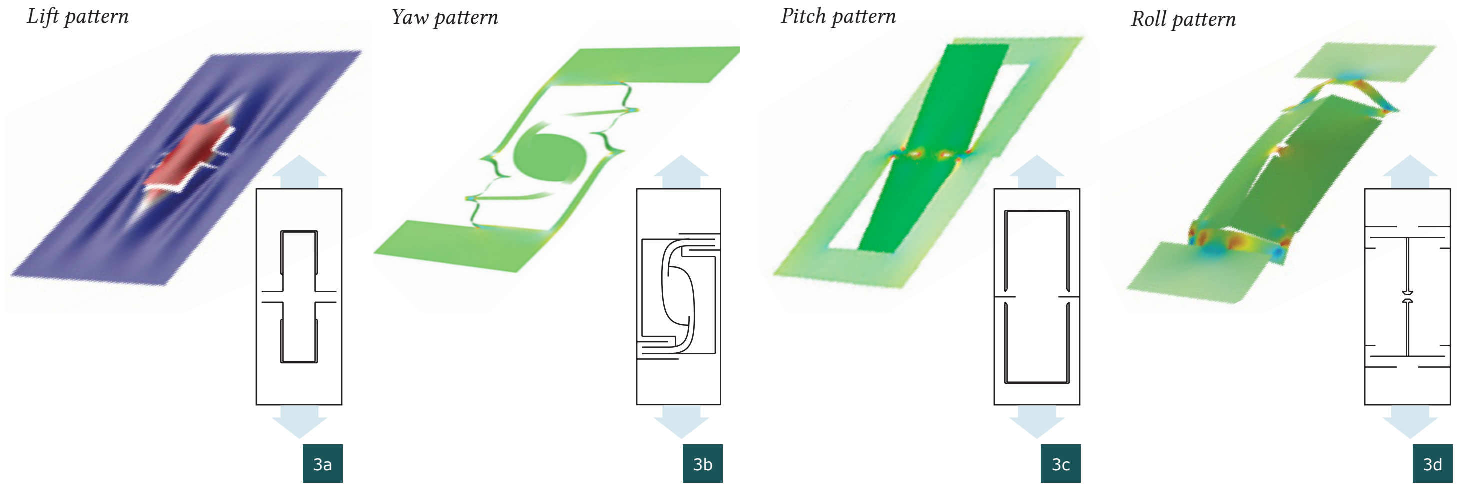
The work presented in this Pictorial, is inspired by, and continues the work of Dias et al. [7] on Kirigami Actuators. It also shares similarities with the work of both Wigdor [3] and Rivera et al. [16], as they similarly employ a layered material structure approach, to achieve materials with both rigid and bendable areas, either through laser cutting of stacked material sheets at varying depths [3], or through 3d printing directly onto textiles [16].

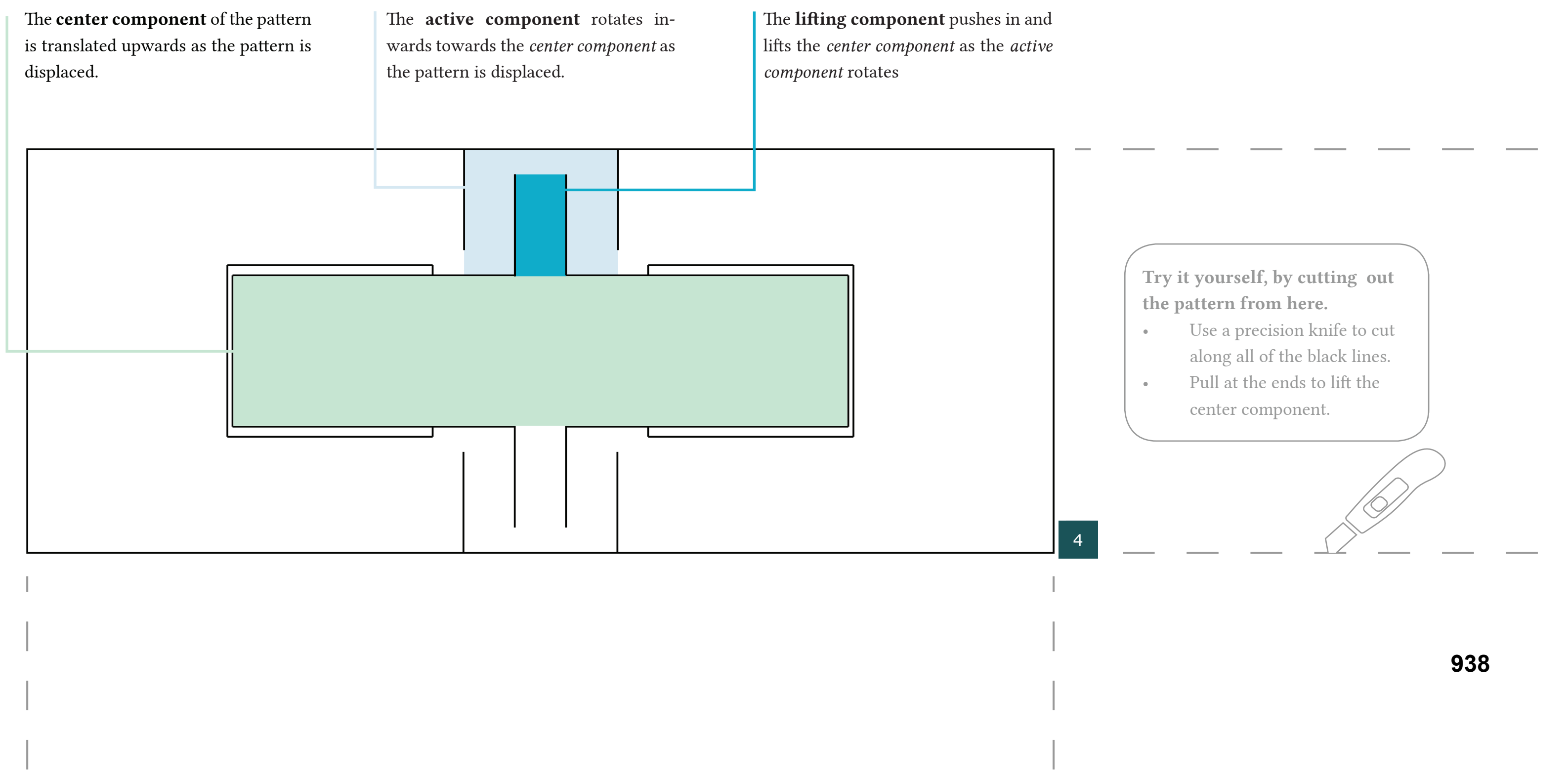
KIRIGAMI ACTUATORS

The work presented in this pictorial builds on the concept of Kirigami Actuators, developed by Dias et. al. [7]. The paper shows how the traditional Japanese art of folding and cutting paper to create three dimensional structures called kirigami, can be utilised to create actuators. Dias et al. illustrate how carefully placed cuts in a thin elastic sheet, can achieve four fundamentally different modes of movement; lift (Figure 3a), yaw (Figure 3b), pitch (Figure 3c), and roll (Figure 3d). All of the four types of transformations are achieved through the same linear displacement. Each of the four patterns was produced by Dias et al. in thin sheets of mylar, as the actuation rely on the ability of the thin material to bend, in order for the actuation to work.

Consequently, it is necessary to make adaptions to the pattern, in order to make it work in thicker or stiffer materials. In figure 4, a detailed cutout pattern of the Lift actuator can be seen, along with an explanation of the sections, or components, of the actuator. The pattern is an adaptation of the one found in figure 3a, and is the basis for the design experiments presented in the following section.

Figure 3: The four patterns introduced by Dias et. al. [7] are shown in colour. Each corresponding cut pattern is shown in black.





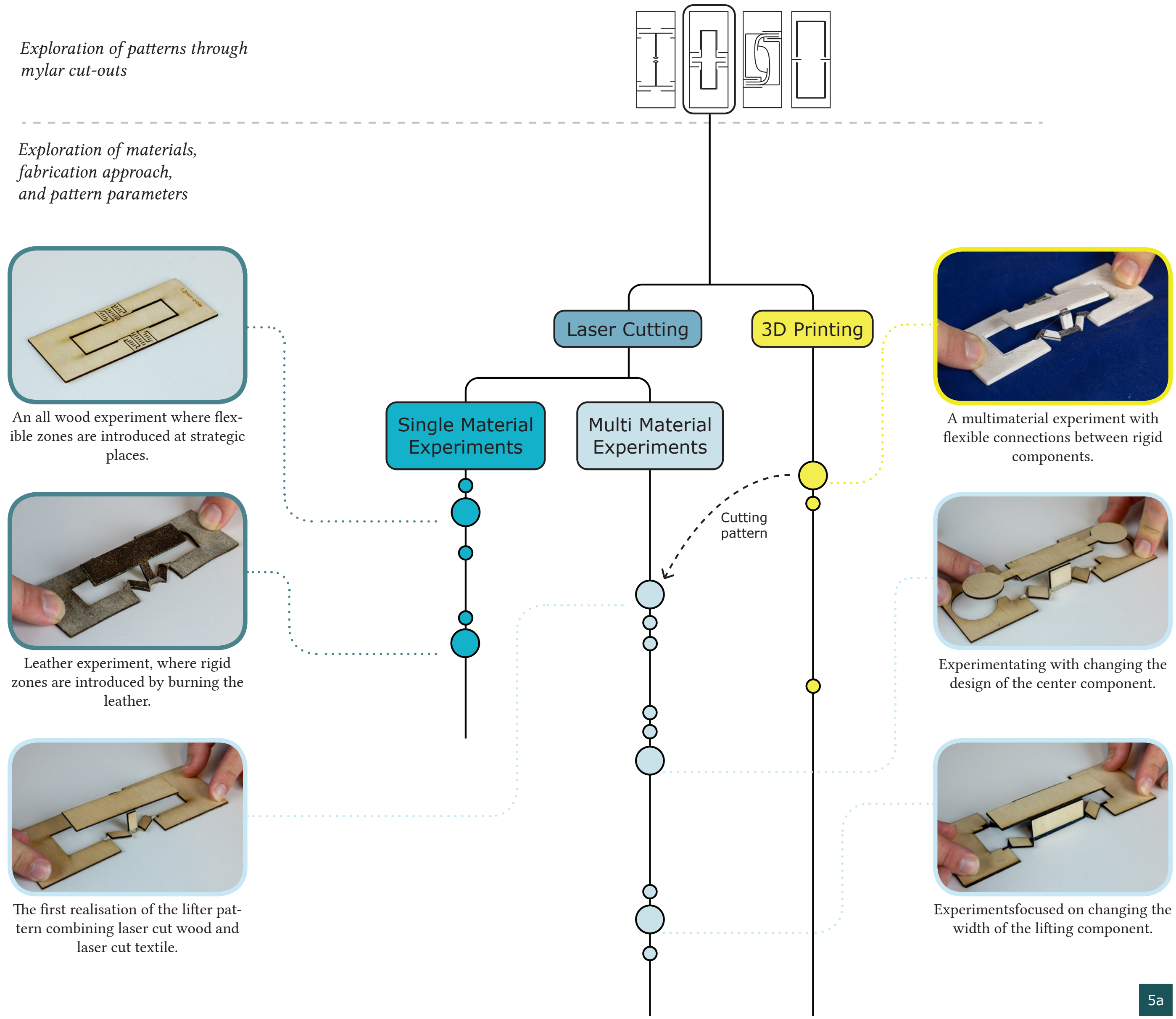
DESIGN PROCESS

Figure 5a+b provides an overview of the design research process, illustrating the different phases (separated by horizontal lines), fabrication techniques (vertical tracks and colors), and specific experiments (the circles). The dotted lines between experiments, represent findings where one experiment directly inspired solutions in a different track.

The first phase of the design process, focused on recreating different patterns and combinations of patterns from Dias et al. [7] in thin sheets of mylar and paper, in order to gain hands-on experience with the patterns.

The second phase explored the Lift pattern through a combination of laser cutting and 3D print fabrication techniques, for quick iterations experimenting with different pattern parameters. Starting out, experiments were loosely defined, but as insights into the three components of the pattern increased, the experiments became more focused.

The last phase focused on synthesizing insights into design tactics, which support future designers in taking advantage of Kirigami Actuators. The tactics illustrate how strategic changes to the different components of the pattern, lead to certain changes in its transformational qualities.



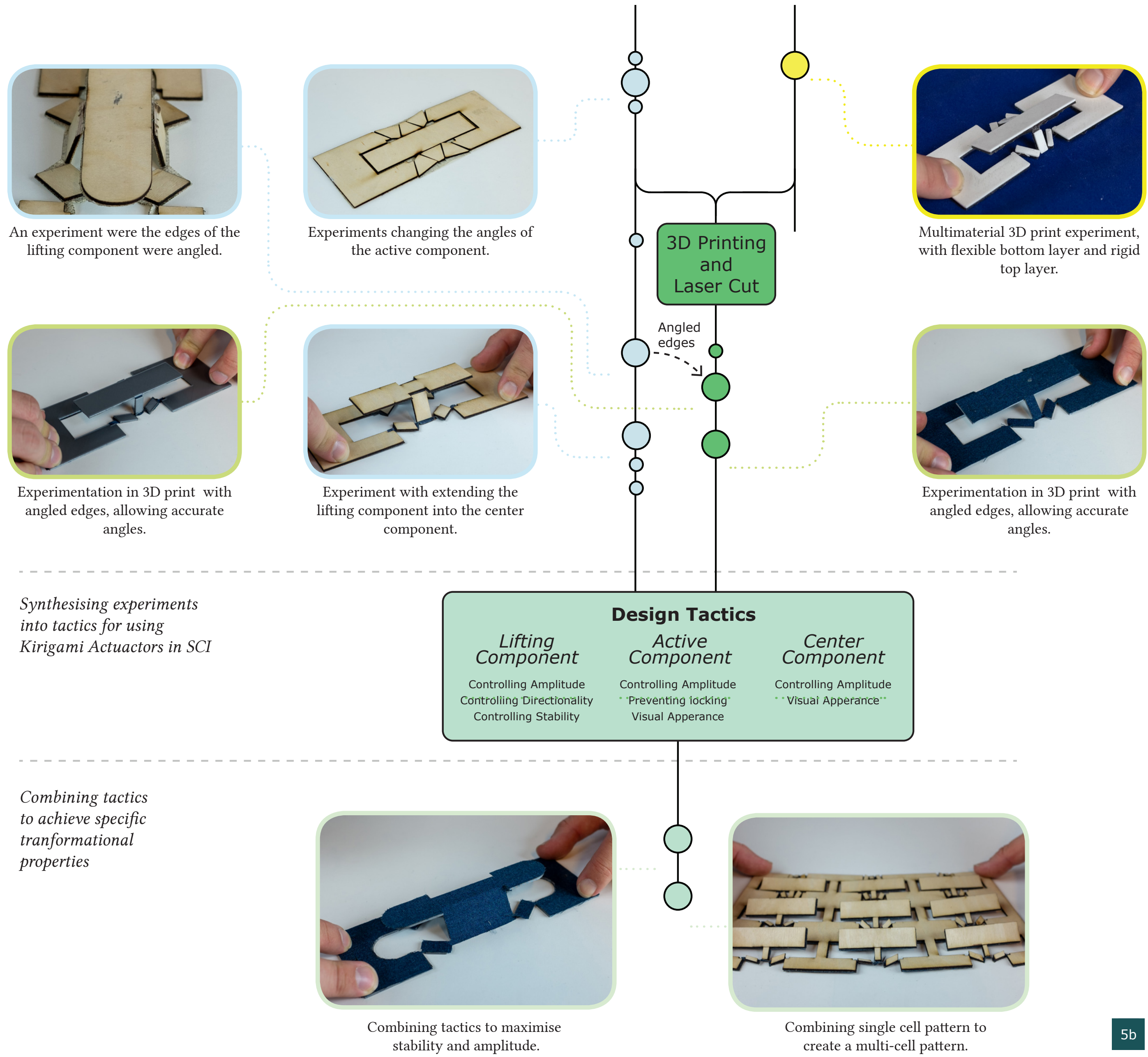
To illustrate how the different tactics can be combined to achieve specific transformational properties, a final kirigami pattern was produced, combining tactics to maximize stability and amplitude.

Furthermore, a multicell pattern was created to illustrate how single cells of Kirigami Actuators can be combined to create more complex actuation.

Alternative Materials & Fabrication Techniques

The experiments presented in this pictorial mainly feature patterns constructed of textile, in combination with either wood or 3D printed plastic. However, as seen in the dark blue track, experiments with leather as a medium were also carried out. The leather was engraved using a laser cutter to introduce rigidity. In the yellow track, experiments using multimaterial 3D print can be found. For these experiments, a sandwich construction of rigid and flexible material akin to C & Wigdor [3], was used.

The patterns were manually assembled, which offered a quick, but also imprecise and laborious way to produce the Kirigami Actuators. Related work, such as the Foldem sheet by C & Wigdor [3], or 3D printing directly on fabric as inspired by Rivera et. al [16], could allow designers to fabricate Kirigami Actuators, with little to no post-processing. All files needed to reproduce the actuators can be found here: bit.ly/kirigami-actuators



An experiment were the edges of the lifting component were angled.

Experiments changing the angles of the active component.

Multimaterial 3D print experiment, with flexible bottom layer and rigid top layer.

Experimentation in 3D print with angled edges, allowing accurate angles.

Experiment with extending the lifting component into the center component.

Experimentation in 3D print with angled edges, allowing accurate angles.

Combining tactics to maximise stability and amplitude.

Combining single cell pattern to create a multi-cell pattern.

ADDING THICKNESS

To understand the deformations and properties of the Lifter pattern, the pattern was produced in paper, as seen in figure 7. Seeing bends and deformations in specific regions, while others remained relatively straight, led to the introduction of two separate layers for flexible and rigid materials as illustrated in figure 6. This is also what led to the exploration of the effect of changes to the different pattern components.

The two layers have distinct patterns, as seen in figure 6. The flexible pattern is identical to the adapted Lift pattern from figure 4. The rigid part was designed with the earlier paper patterns in mind, placing rigid material, where the paper remained straigth. This relationship can be seen by comparing figures 7 and 8.

Working Kirigami Actuators were produced with 2mm material thickness, e.g. the actuator from figures 8 and 10. Thicker versions up to 4mm were explored, as seen in figure 9. Findings from these explorations revealed that the possible thickness of the pattern is limited. Because of the material thickness, the active components catches on to the centre component as it moves upwards, and they move inwards. This might be avoided by increasing the space between the center component and the active components, in turn, affecting the overall dimensions and possibly the behaviour of the pattern. No further explorations were made into increasing the material thickness of the actuator.

Actuating the pattern

To actuate the Kirigami Actuators electronically instead of manually, a simple interactive prototype was built, shown in figure 10. Two small linear actuators were placed along the top of a clear acrylic box. When moving the linear potentiometer a microcontroller moves the actuators in- or outwards, in turn lifting or lowering the Kirigami Actuator attached.

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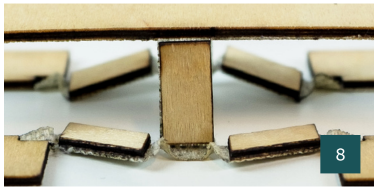

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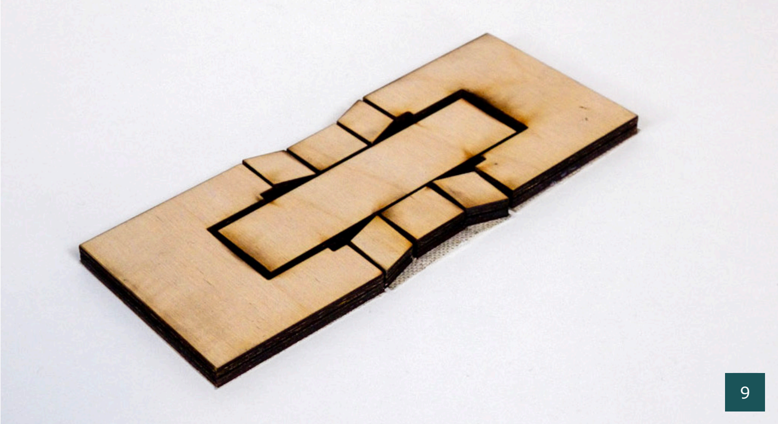

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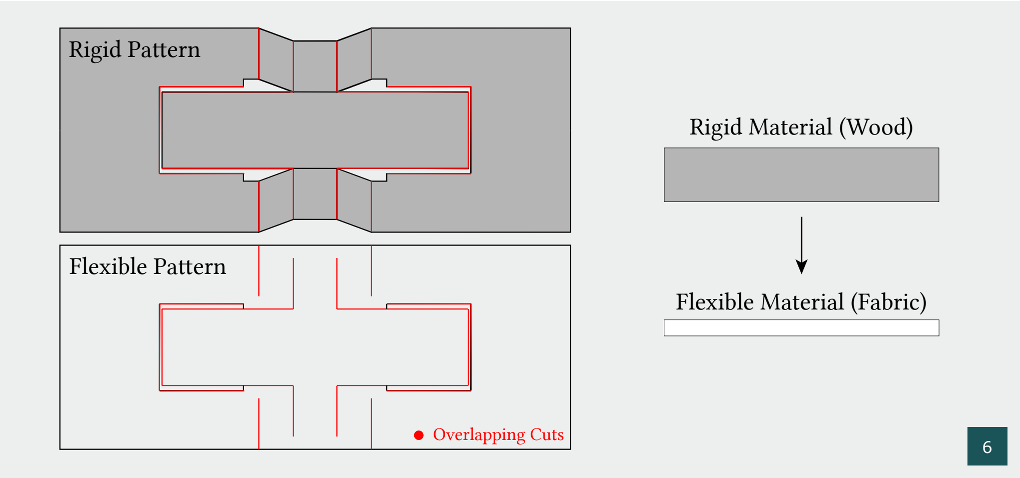

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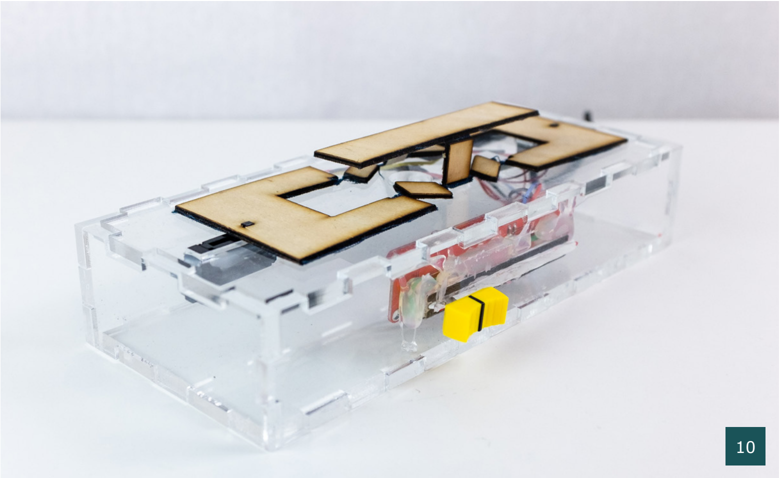

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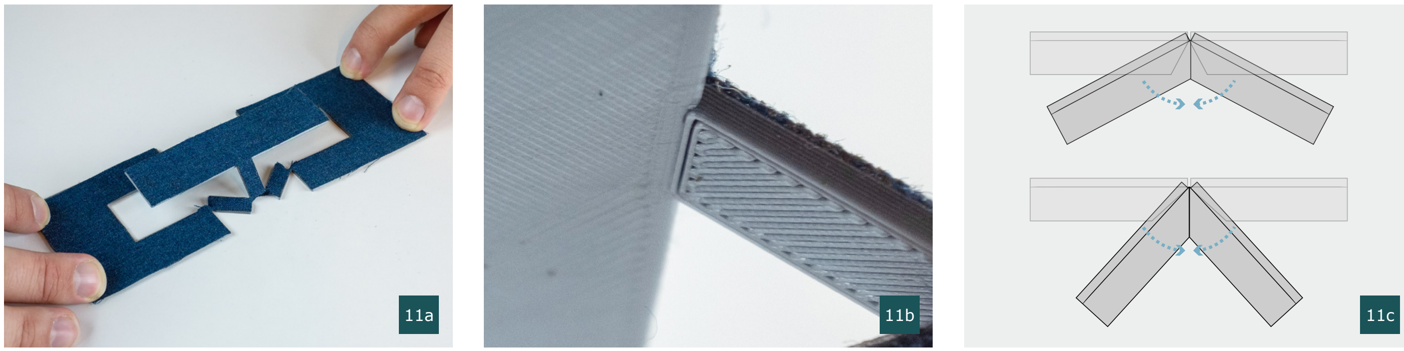
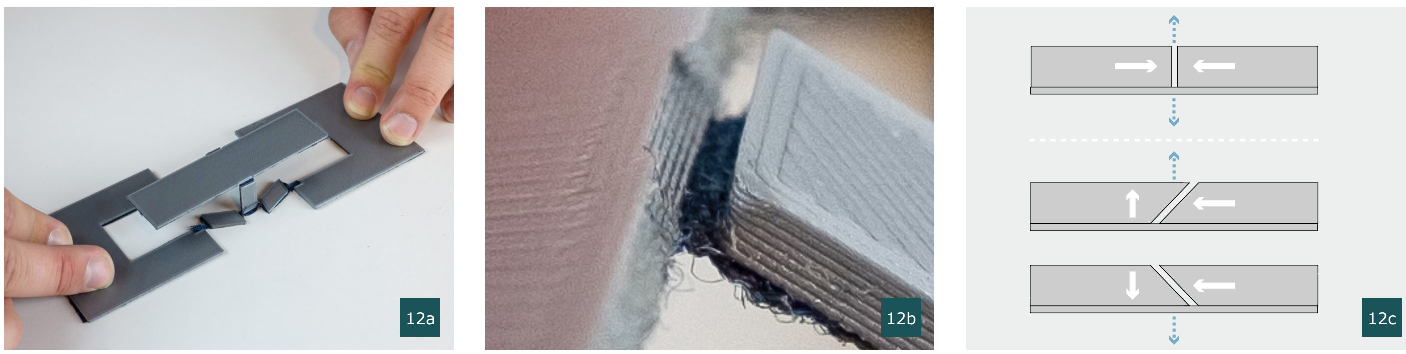
THE LIFTING COMPONENT



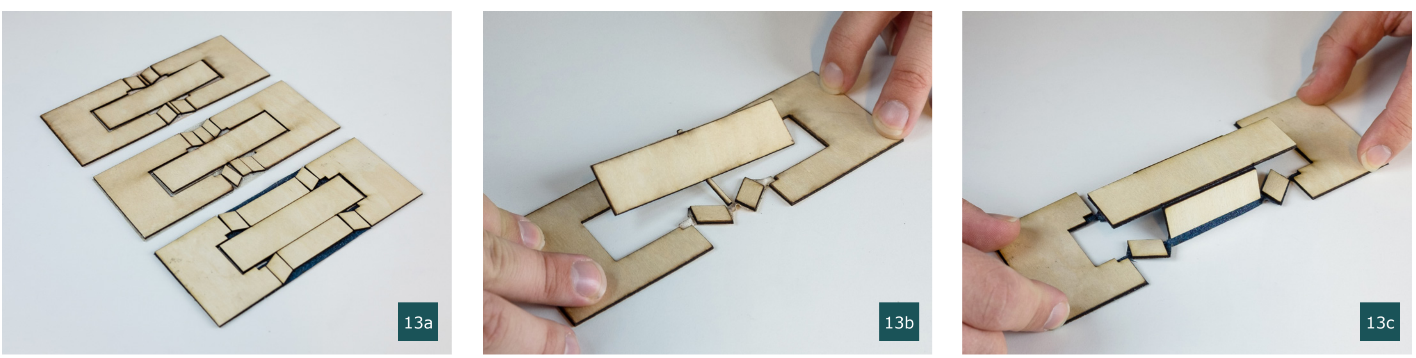
Controlling Amplitude

By introducing an angle, where the lifting component meets the center (figure 11b), the amplitude of the translation can be controlled. Maximum lift is achieved when the combined angle between the lifting and center component is 90° and any acute angle limits the amplitude. Introducing an angle also increases the stability of the center component.



Controlling Directionality

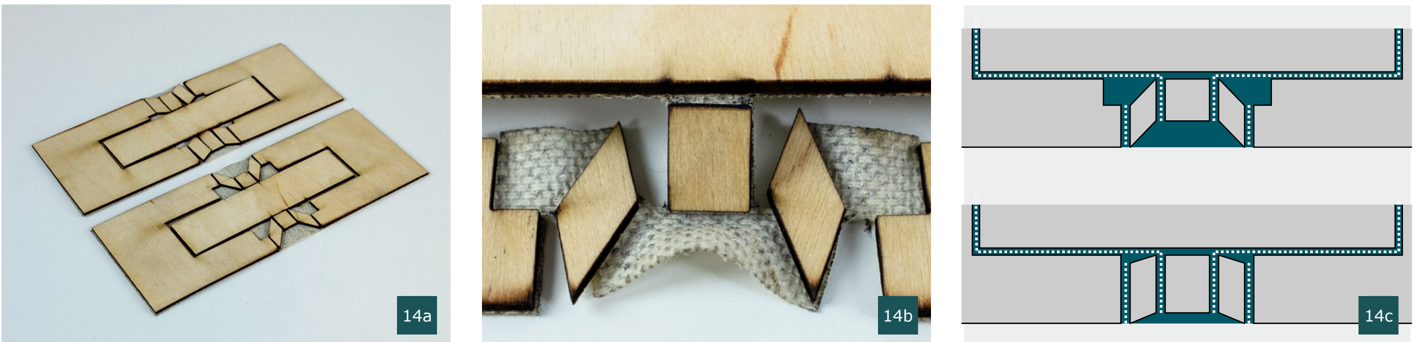
When the edges between the lifting and center component are straight, the direction of actuation is uncertain – it can move either up, down, or lock. By implementing parallel angles (figure 12c), the direction of the translation can be controlled – as the angles directs the force (indicated by the white arrows).



Controlling Stability

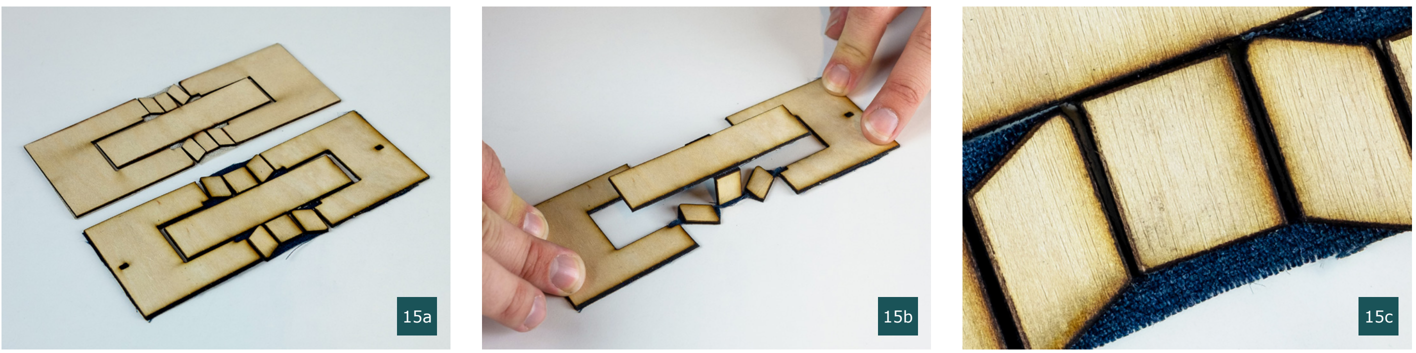
Changing the width of the lifting component (figure 13a) leads to an increased stability of the center component in one dimension (figure 13c). As the force from the weight of the center is dispersed across the width of the lifting component, the width is directly related to the stability.

THE ACTIVE COMPONENT



Controlling Amplitude

Changing the relation between the cut lengths (figure 14c) in the active component, controlls the amplitude of the translation (figure 14b). Maximum translation is achieved when the active components rotate 90°. Shortening the cuts limits the amplitude, but too long cuts can make the construction fragile.



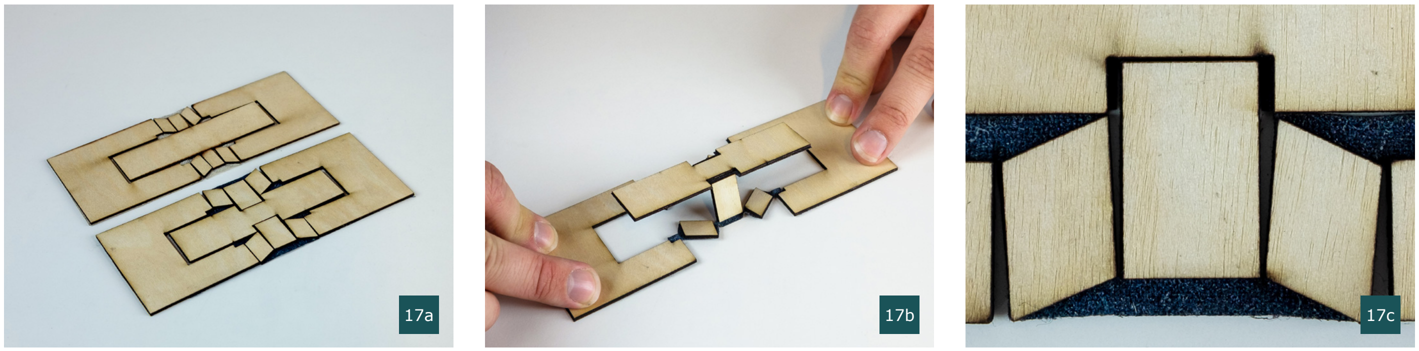
Preventing Locking

During actuation, the active component is pushed inwards, which in some cases causes it to lock the center component in place. Rounding the corners (figure 15c) of the active area prevents this, and the movement of the active component becomes less constricted and more smooth.

Visual Apperance

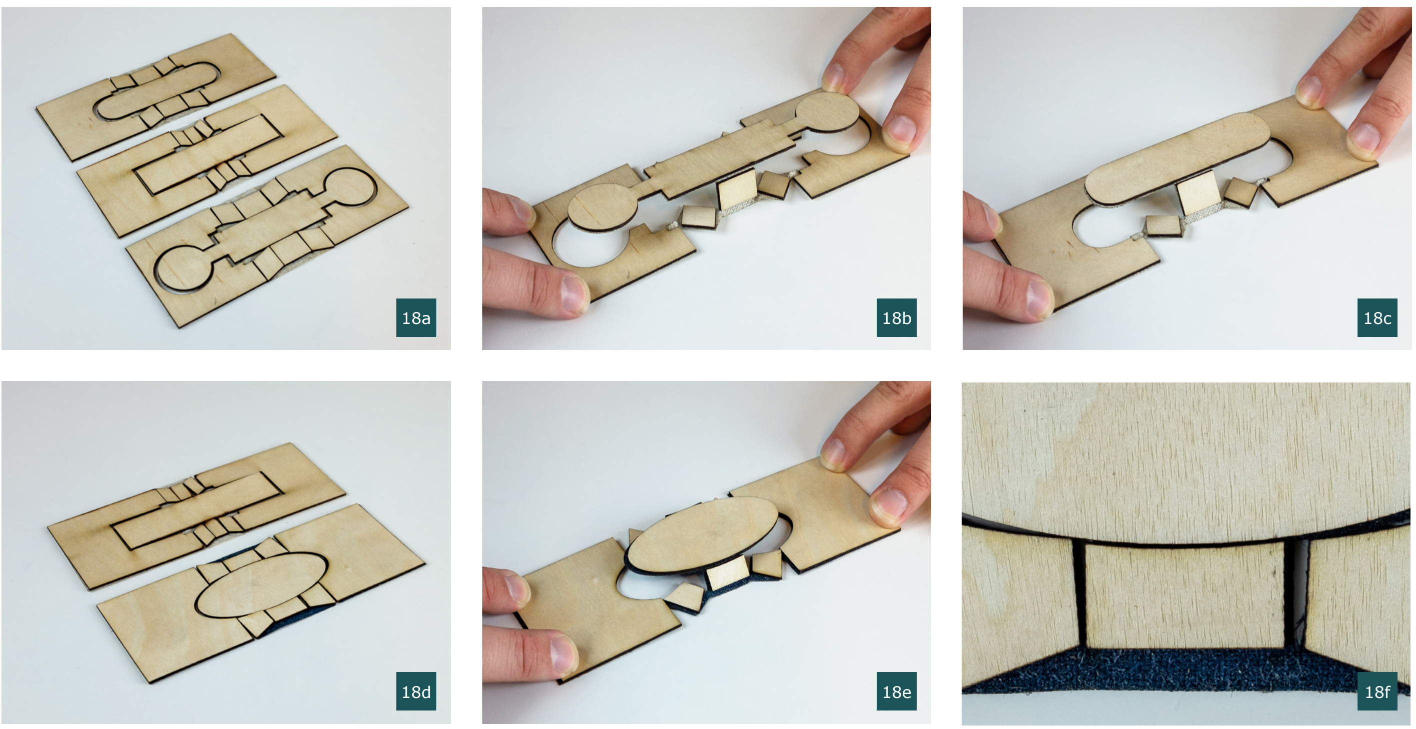
The visual appearance of the active component can be significantly altered with little to no impact on the actuation, as long as the overlapping cuts seen in Figure 6 are maintained. The pattern works with a variety of angles (see Figure 16a-c), the two active components on either side of a kirigami actuator do not need to be symmetrical for the actuation to work.

THE CENTER COMPONENT



Increasing Amplitude

As seen in former experiments, the length of the lifting component governs the maximum amplitude of the translation. However, the maximum amplitude can be increased without altering the total width of the pattern (figure 17a), by altering the center component (figure 17c) to allow for a longer lifter component.



Visual Apperance

The form of the center component can be designed with relative freedom (see Figure 18a). However, while the ends of the center component can be changed to effectively any shape, challenges can occur as seen in Figure 18b, where the shape when actuated occasionally causes the components to interlock and inhibit actuation.

The appearance of the middle part of the center component can also be changed from straight to a slight curve, while still being able to function (Figure 18d). Since the active area remains largely the same, force is still translated upwards. The textile used in the structure is capable of bending reliably, in spite of the curve (Figure 18e).

REFLECTIONS

This section reflects on combining multiple tactics into one pattern and on designing multi-cell patterns. Reflections on possible uses of the Kirigami Actuators in SCI are presented through concept sketches and finally reflections on bridging SCI and Material Science and Engineering are presented.

Using and combining tactics

Figure 19 presents an example of how tactics can be combined to maximise stability and amplitude. In the actuator in figure 19, stability is increased by widening the lifting component, as suggested in Figure 13, as well as introducing angled edges between the lifting- and center components, as seen in figure 11. The amplitude is increased by extending the lifting component into the center component, as suggested in figure 17. To avoid that the components lock when actuated, the corners on the active components are rounded, as seen in figure 15.

Multi-cell Patterns

Dias et al. [7] illustrate that the Kirigami Actuators also work in multi-cell patterns as seen in figure 20.

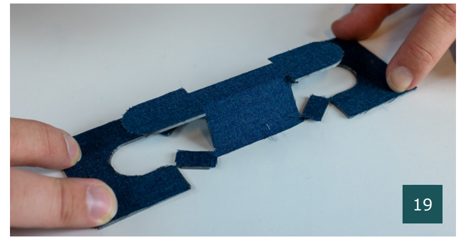
The principles driving the multi-cell lifter pattern, are the same as in the regular single-cell pattern. The active components push into the lifting components, forcing the center components to translate upwards. Since there are multiple active-, lifting- and center components, these can be designed individually, by using different tactics for different cells. Using small multi-cell patterns, designers could potentially produce surfaces with complex changeable textures.

Another possible feature of the multi-cell pattern is the ability to direct displacement by changing the point of actuation. As seen in figure 20, actuating the ‘top end’, will initially actuate the top row with higher amplitude than the center row, which again has higher amplitude than the bottom row.

Possibilities for SCI

Using Kirigami Actutators as opposed to regular linear actuators opens new avenues to pursue when designing shape-changing interfaces. As Kirigami Actuators require very little space underneath them, they might be used to design actuated surfaces, where the thickness of the surface is limited. An example of such a surface can be seen in figure 21. Using Kirigami Actuators one could design everything from deformable surfaces to protruding interactive elements like buttons without adding undesireable thickness from electromechanical components otherwise required to actuate them.

In figure 22, a concept sketch of a shape-changing dining table can be seen. By utilising Kirigami Actuactors such a table could be placed directly onto the floor. Since the translation happens along the floor, the table could be placed in a room without having to dig out a hole for linear actuators.



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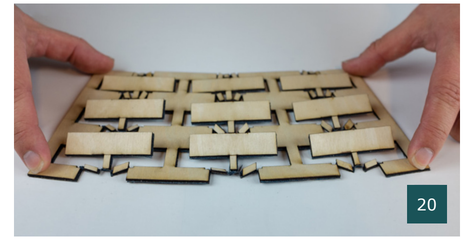

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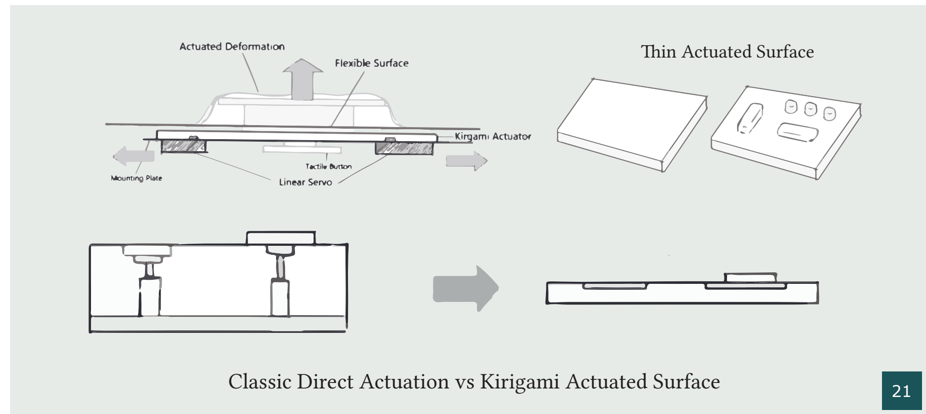

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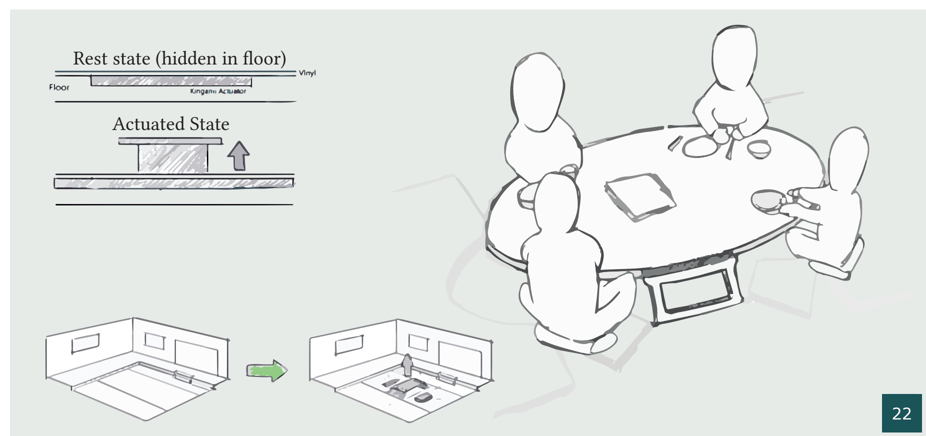

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Bridging SCI and Material Science and Engineering

Generally, research on Shape-Changing Interfaces could benefit from seeking inspiration in both Material Science and Engineering, as research in this area could provide techniques for new and smarter ways to create shape-change in the future. Qamar et al. [15], have already begun paving the way for bridging work on Shape-Changing Interfaces in HCI, with research from Material Science and Engineering.

As this pictorial illustrates, ideas cannot always be directly used as they are presented with Material Science or Engineering, but might require some form of adaption to make it applicable for Shape-Changing Interfaces. To take the full advantage of the potential of bringing these two areas, it is important to establish collaborations, which allow for taking advantage of the skills, knowledge and ways of working from both traditions.

FUTURE WORK

The work presented in this pictorial only addresses the lift transformation from Dias et. al. [7], leaving out the pitch, roll and yaw transformations. For designers of Shape-Changing Interfaces to fully take advantage of Kirigami Actuators, the remaining three types of transformations need to be addressed in a similar fashion. However, addressing the three additional transformations comes with an entirely new set of challenges, since they require large, uneven surface deformations, which entail that the tactics developed in this paper are not directly applicable. Consequently, a similar exploration needs to be carried out for the pitch, roll and yaw patterns. Beyond addressing more Kirigami patterns, further research could explore the generality of the tactics through other materials and fabrication techniques. The potential of multi-cell patterns could also be explored further.

CONCLUSION

In this pictorial we have presented a series of tactics for realising Kirigami Actuators in SCI. The tactics are a product of a constructive design research process, where different adjustments to the Kirigami Lift pattern and material combinations and fabrication approaches have been explored. The presented tactics illustrate how different components of the Kirigami Actuator pattern can be changed, and with what result. Finally, we reflect upon the results, and suggest new directions for research on Kirigami Actuators in SCI and the potential for Bridging SCI, Material Science and Engineering.

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