

# Digital Design and Simulation of Knit Panels for Transforming Scissor Structures

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As architecture faces demands for adaptability, transformable design offers vital strategies for dynamic spatial configurations. This research explores the integration of knitted textiles with transformable scissor grids to create collapsible architectural walls. By utilising the elasticity of knitted materials, the project optimises expansion and retraction of the surface membranes, enhancing adaptability. Digital simulations are used to predict the textile behaviours and informed the material development and patterning. The final design incorporates two offset scissor grids, adding depth and dynamic interplay between colour and pattern. Using nylon yarns and nylon-covered elastic yarns created a range of elastic responses, enabling the membrane to stretch and contract with the transformable grid whilst maintaining tension. This integration enhanced the visual expression of movement, allowing colours and patterns to shift during transformation. The study demonstrates how knitted membranes can infill scissor grids creating enclosure, providing stability, whilst enabling dynamic, responsive surfaces for adaptive architectural design.

#simulation

#fabrication

#digital to physical

#textiles

#transformative design

## Introduction

The demand for adaptable and transformable spaces is driving innovation in materials, structures and design. Deployable structures and kinetic systems address the need for flexibility and dynamic interaction within built environments. These elements can become integral architectural components, such as deployable wall systems to subdivide large spaces for different use configurations, as well as screens or façades that can deploy or transform with shading and environmental demands. This research utilises scissor grid mechanisms with knitted textile membranes to solve the issue of surface enclosure on transformable structures.

In architectural design, the desire to be mobile and kinetic is not new. We have seen nomadic tribes historically developing transformable and portable architectural structures from around the world (King 1988). In the modern era, the interest in reconfigurable architecture has been integral to theoretical work conducted by designers such as Cedric Price in his proposals, including the Fun Palace (Mathews 2006). Further design of the conceptual theories of flexible and adaptive architectural spaces can be found in the work of Yona Friedman (2006). In addition, cybernetic technology can add responsive architectural design elements to create soft architecture from the theories of Nicholas Negroponte (1975).

Scissor mechanisms are basic transformable components that are easily and efficiently expanded and contracted. They are characterised by their interconnected pivoting members and have been utilised in various applications in engineering, industrial design and architecture, ranging from simple expanding mechanisms for light fixtures to complex deployable architectural structures. The work of Chuck Hoberman, who developed the Hoberman Sphere using scissor mechanisms, highlights the potential of these systems to create large, complex and dynamic architectural forms that can expand from compact configurations to large forms

(Hoberman, 1990). Notably, the features of these structures are made up of linear members and often fail in their ability to enclose space. The movement of a scissor mechanism requires a wide range of shape changes, which typical rigid surface materials cannot perform. Meanwhile, standard textiles with low elastic properties are not a good option because they will begin to bunch and wrinkle when the form is moving, which can get in the way of mechanisms, hindering their ability to transform.

Therefore, further advancements in textiles have opened up new pathways for architectural applications. With properties such as flexibility, strength and lightweight characteristics, textiles are ideal for integration into moveable structures. Research into tensile architecture, exemplified by Frei Otto's (1973) work on tensile membrane structures, has demonstrated how membranes can be used to create expansive and visually stunning architectural forms. In these cases, they were utilised for efficiency and were not intended to be mobile but rather pulled tightly into permanent tension.

Knitting, in particular, has become a significant area of contemporary architectural research due to its bespoke fabrication capabilities and inherent elastic properties. Architects and designers such as Mariana Popescu, Jenny Sabin and Mette Ramsgaard Thomsen have explored knit's potential to create intricate, responsive structures. Some of Popescu's work has investigated how knitted formwork can be used in concrete casting, combining flexibility with structural integrity (Popescu, 2019). Sabin's 'Lumen' installation showcases how a large-scale knitted textile canopy and structure can respond to environmental stimuli, creating interactive architectural elements (Sabin, 2017). Thomsen's (2015) research on the integration of computational design with textile techniques pushes the boundaries of material and form in architecture. These and other explorations into knit as an architectural material highlight knitting's versatility and its ability to produce structures customised to various functional and aesthetic requirements.

Combining two domains of research – deployability and knitted textiles – this project explores how textiles can provide the need for surface enclosure in transformable structures. Knitted textiles, with their inherent elasticity and adaptability, present a good option for creating flexible enclosures for complex transforming shapes, such as in a scissor grid. The elasticity of knitted fabrics allows them to expand and contract with the movement of scissor mechanisms, providing both structural stability and aesthetic fluidity.

The integration of digital simulations and physical fabrication processes is crucial in realising the potential of these transformable structures. Digital tools such as Rhino and Grasshopper enable precise modelling of scissor mechanisms and textile behaviours, allowing for the optimisation of material choices and structural configurations before physical prototyping. Smaller samples allow the testing of these designs at scale to confirm and make necessary adjustments before producing the final results. This iterative process ensures that the final designs are functional.

In his book *Materiality of Architecture*, Antoine Picon addresses how digital design has changed our relationship with materials and how there is a demand for the development of architectural materials that have unique dynamic and performative qualities with technology (Picon, 2018).

This research contributes to the field of architectural design by filling the demand for the creation of designs that are transformable and adaptable. The scissor structure mechanisms are not new technology but are lacking in their ability to enclose space by having difficulty providing surface material that can transform with this movement. This research shows how the workflow between digital simulations and physical fabrication is necessary to lead to innovative, adaptable structures. As the demand for flexible and dynamic architectural solutions continues to

grow, this study provides valuable insights into the potential of combining scissor mechanisms with textiles to create responsive, transformable and adaptable spaces.

## Methods

This research took a project-based approach, progressing from small-scale studies and digital simulations to larger-scale prototypes and testing. The involved a cyclical process of design, simulation, fabrication and evaluation, ensuring a thorough exploration of materials and their performance within the scissor grid structures.

**Small-Scale Studies and Initial Prototyping.** The initial phase of the research focused on small-scale studies to understand the interaction between scissor mechanisms and knitted textiles. Various yarn materials, knitting patterns and attachment strategies were tested on small samples to assess their impact on deployability and material constraints. These small-scale prototypes allowed for rapid iteration and hands-on experimentation, providing valuable insights into material behaviour and dynamics (see Figure 1).

**Digital Simulations.** Concurrent with small-scale physical prototyping, digital simulations played a crucial role in predicting and optimising the performance of the scissor grid structures. Using Rhino and Grasshopper digital modelling software, the scissor mechanisms and textile behaviours from the small-scale models were precisely digitally replicated. These simulations enabled further prediction of the expansion and contraction dynamics, identifying potential issues and allowing refinement of the designs before moving to larger-scale prototypes (see Figure 2).

The digital tools facilitated a variety of explorations of different configurations and material combinations, allowing for the prediction of how knitted textiles would interact with full-scale scis-

sor mechanisms. The simulations also provided data on stress distribution, elasticity and overall structural performance, which were essential for optimising material choices and ensuring the stability and functionality of the final designs.

Various design patterns and material arrangements were tested to study the different effects on movement and design applicability (see Figure 3). The designs were simulated digitally as well as through various small-scale models, providing a cyclical feedback loop between the digital and physical designs throughout the development process. This helped refine the results and build a deeper understanding of the properties of knitted materials.

**Larger-Scale Prototypes.** Based on the insights gained from the small-scale studies and digital simulations, two larger, human-scale prototypes were developed. These prototypes were designed to test the scalability of the scissor grid structures and the full-scale performance of the knitted textiles. The larger prototypes incorporated two layers of offset scissor grids, creating depth and dynamic interactions between the materials and patterns.

The knit materials used in the larger prototypes combined nylon yarns and nylon-covered elastic yarns, providing a range of elastic properties. This combination enabled the textiles to expand and contract with the scissor mechanisms, ensuring both structural stability and aesthetic fluidity. The larger-scale prototypes were evaluated for their ease of deployability, overall stability and seamlessness of movement, with adjustments made as necessary based on the testing outcomes.

**Evaluation and Iteration.** Throughout the research process, the prototypes were subjected to evaluation and assessment of their performance to identify areas for improvement. Throughout the iterative approach, continuous refinement of the material designs ensured that the final prototypes met the desired functional and aesthetic criteria.

The evaluation criteria included ease of deployment and retraction, the smoothness of the textiles under various states of transformation and the visual dynamics of the knitted textiles. Feedback from these evaluations informed subsequent iterations, with adjustments made to the scissor mechanisms, knitted textile materials and attachment strategies as needed.

## Knitting

The knit material used in this project was a rib knit. This basic knit stitch pattern was selected for its elasticity compared to other knit patterns in the preliminary testing. Rib knitting is characterised by alternating knit and purl stitches, which create ribbing in the fabric that allows for easy expansion and recoil. This elasticity in the knit structure is useful for application within scissor grid structures, where the material needs to accommodate significant movement without losing its material integrity.

**Material Composition.** To add even more elasticity to the knitted textile and provide the stretch needed, the knit panels were fabricated using striped rows of nylon yarns and nylon-coated elastic yarns. This combination provided varied stretching properties essential for the project's movement. The nylon yarns offered strength and stability, while the nylon-coated elastic yarns contributed to further flexibility and recoil. This combination of stripes in the course (or row) direction balanced the materials' natural elasticity. As knit materials tend to stretch more in the course direction rather than the wale (or column) direction, given the looping nature of knit materials' construction, by strategically alternating these materials, the resulting fabric could stretch and retract as needed, ensuring a responsive interaction with the scissor mechanisms.

The main goal of the refinement of the knitted textile was to provide elasticity across the material and in various directions. Given that knitted mate-

rials are heterogeneous and do not act the same in each direction when forces are applied, the pattern of materials and stitch type are intended to balance these effects. Furthermore, the material needed to meet the demands of movement with the scissor structure design within its elastic range, reducing any wrinkling or overstressing to seamlessly create a surface membrane for the scissor grid.

**Pattern Development.** The development of knit stripe patterns began with the use of Rhino and Grasshopper to develop an understanding of the geometries needed to accommodate the dynamic movements of the scissor grid structure. The stripe pattern and rib spacing were designed to create the most effective design and balanced pattern that would adjust to these geometric transformations. Meanwhile, the pattern was developed with consideration of aesthetic qualities as well as ease of fabrication.

These digital pattern designs were then exported as pixel patterns that could be interpreted by CNC or manual machine knitters. For CNC knitting, the pixel patterns were translated into machine code that directed the knitting process, ensuring precision and consistency. For manual knitting, a key was developed to guide the knitter in accurately following the pixel pattern, allowing for the production of bespoke knit panels (see Figure 4).

**Fabrication Process.** The fabrication of the final knit panels involved manual knitting due to the accessibility and cost of CNC knitting machines. Using a Passap Duomatic 80 knitting machine, the pixel patterns were manually implemented using a knitter. This required tedious attention to detail regarding when to change yarns and in setting up the various yarn tensions, stitch lengths and stitch types, as well as a tedious casting on and off process to start and finish each panel.

Each panel was carefully knitted to match the digital designs. The resulting knit panels were stripe pattern

is playful, with their use of colour creating aesthetically pleasing and a functionally effective design capable of expanding and contracting in harmony with the movements of the scissor grid structures.

For the two walls developed to test the design hypothesis, several panels were required to knit. Although these sets of panels took multiple hours to fabricate, the knitting machine's manual process was simple and conducted easily, and it allowed for adjustments if any errors emerged. This was due to keeping the design pattern as simple stripes, which are easy to fabricate with the row-based fabrication method of knit materials.

By employing rib knitting and a strategic combination of materials, the resulting knit panels achieved the desired balance of strength and flexibility. The preparation of the patterns in digital design tools and advanced knitting techniques created a positive result in achieving the required material properties for the project panels. This approach highlights the potential of relying on digital simulations to design and develop knitting panels with good predictability for transformable architectural applications, for which customisability and the material's elastic performance are integral.

The final tests were conducted to develop several panels for two different wall designs, with the same scissor grid design used and different panel arrangements tested to prove the efficacy of the knit material's size, shape and pattern to be manipulated to successfully work in various configurations.

## Diagonal Scissor Wall

**Diagonal Design Process.** The first wall design responded to the organisational structure of the scissor grid to incorporate knit panels aligned along its members. The grid's  $3 \times 3$  configuration resulted in diagonal panels, creating an arrangement of three types of knit panels to fit diagonally:

one long panel spanning the entire structure from corner to corner, two medium-sized panels and two smaller panels filling the remaining grid squares. Each panel was knitted using the rib and striped knit patterns developed for the project using Grasshopper.

Once all 10 panels (five for the front and five for the back) were knitted, they were attached to the two offset scissor grid structures, spaced approximately 20 cm (eight inches) apart using threaded rods. The scissor grids were made with wood strips, which were at the longest members, with a length of two metres (six feet). The offset configuration allowed the back panels to infill with knitted pieces orientated diagonally in the opposite direction from the front panels, creating a balance of forces and depth in the design. The front panels were knitted with red nylon yarn and white nylon-covered elastic yarn, while the back panels were knitted with blue nylon yarn and white nylon-covered elastic yarn. The offset diagonal patterns of the knit panels contributed to a layered aesthetic, enhancing both depth and complexity.

## Results

During the transformation of the scissor grid from a collapsed position to an expanded position, the knit material stretched at angles, causing deformation in the textile stripes. This deformation produced warped patterns as the material skewed and torqued. The front and back stripes stretched in opposite but complementary directions, adding a dynamic quality to the wall (see Figure 5). During this deployment, the wall transitioned smoothly between a collapsed and a fully expanded state. The material successfully stretched and transformed into shape without causing wrinkling or strain. The depth provided by the spacing of the threaded rods allowed the wall to stand independently without additional support (see Figure 5).

However, the tension on the knit material's sizing was slightly too taut, so fully collapsing the wall

in either direction placed significant tension on the knit fabric, requiring a little more force to achieve the collapsed position. This made the open deployed state of the wall the most relaxed and stable position since it minimised the stress on the knit material and created a state of equilibrium in the tension on the material.

## Reflections

The diagonal wall design demonstrated the potential for integrating knitted textiles within scissor grid structures. Aligning the panels with the grid members and using a strategically designed stripe knit pattern of varied elastic materials resulted in a visual representation of the wall's movement and function. The dual-layer configuration, with panels orientated in opposite diagonals, added depth and balance to the design, enhancing both its aesthetic and performative qualities.

Key observations included the uneven deformation of the knit material through the stripes during movement, which added a dynamic and visually interesting element to the wall. This characteristic underscores the importance of material selection and pattern design in achieving both aesthetic and functional objectives. The tension experienced during full collapse highlights the need for further refinement in balancing material elasticity and structural movement. Future designs could benefit from adjusting the scissor grid member spacing, exploring alternative attachment strategies and reducing the force required for collapse.

## Orthogonal Scissor Wall

### Process

The second wall design contrasted the knit panels with the diagonal arrangement of the scissor grid, creating a different type of interaction and movement in the materials. This alignment meant that

as the panels stretched to fit across the grid, the middle sections of the panels were pulled to fill the diamond-shaped spaces formed by the scissor mechanism. This resulted in more significant warping and distortion expressed in the striped knit material as the elastic yarns stretched to conform to the new shapes.

The fabrication process involved creating 10 panels: three large ones and two medium ones for each of the front and back layers of the wall. The knit patterns for these panels were also developed using Rhino and Grasshopper to ensure control over the elasticity of the stripes. Due to the different orientations of the material, the patterns, size, shape and elastic properties had to be adjusted for this configuration. In this case, the patterns added a few extra stitches, having learned from the previous design, which, in reflection, was too taught. These panels utilised warm tones of red and yellow nylon yarn on the front and back panels, featuring cooler tones of blue and green. This choice of colours again emphasised the visual dynamics of the design as the contrasting colours interacted through the layers (see Figure 6).

Each panel was again knitted manually, allowing control over the transition of the striped materials. The process was manual and involved tedious steps to maintain the material's details. The finished panels were then attached to the scissor grid structure, with the large panels filling the vertical spaces on the front and the horizontal spaces on the back. The medium panels were then infilled, crossing those to fill the middle panels. This arrangement allowed the panels to cross over each other, enhancing the complexity and depth of the material arrangement.

## Results

This contrasting alignment of the panels with the orthogonal orientation resulted in the unique and dynamic movement of the materials. From

the original digital simulations, the knit material behaved slightly differently and was more pinched and warped than expected. As the scissor grid was expanded and contracted, the middle sections of the panels were pulled to fit within the diamond-shaped spaces, causing the striped patterns to warp and curve. This created a visually engaging effect – almost hypnotic – with the elastic yarns stretching and the stripes taking on new curved forms (see Figure 7).

When the front and back panels were combined, the use of distinct colours further amplified the depth and variation. The warm tones of red and yellow on the front contrasted with the cool tones of blue and green on the back, creating a vibrant interplay of colours as the wall moved. The dynamic movement and colour changes added a new level of complexity and interest to the design, making the wall not only a functional element but also an aesthetic statement and visually expressing the forces and strain in the material.

## Reflections

The second wall design successfully built upon the insights gained from the first iteration, introducing a new alignment and colour scheme that further enhanced the dynamic properties of the material. The orientation of the panels, combined with the use of elastic yarns, created a warped pattern that emphasised the flexibility and adaptability of the knit materials.

The warping and curving of the stripes as the panels stretched added a layer of expression and demonstrated the stresses and strain on the material. The contrasting colours for the front and back panels further enriched the design, highlighting the interplay of colour and form and expressing the variation of movement between the front and back panels.

Overall, the second wall design expressed the success of another arrangement of knitted textiles to create dynamic architectural elements. The process reinforced the value of iterative prototyping and the integration of digital and physical design methodologies since the second prototype implemented learned information from the first iteration. The success of this design highlights the potential for more development and design to utilise knitted textiles as surface membranes that can transform with complex geometrical movements.

## Conclusion

This research tested the potential of using knitted textiles to create enclosures within a transformable scissor grid frame structure. The project was a test of further demands for deployable and transformable architectural elements. The role of digital tooling in the design and fabrication process highlights how digital modelling and simulation using Rhino and Grasshopper is integral to the design process to create complex specified patterns for the knit panels. These tools not only facilitated the initial design phase but also allowed for accurate prediction and control over the material behaviour, ensuring that the final designs functioned smoothly.

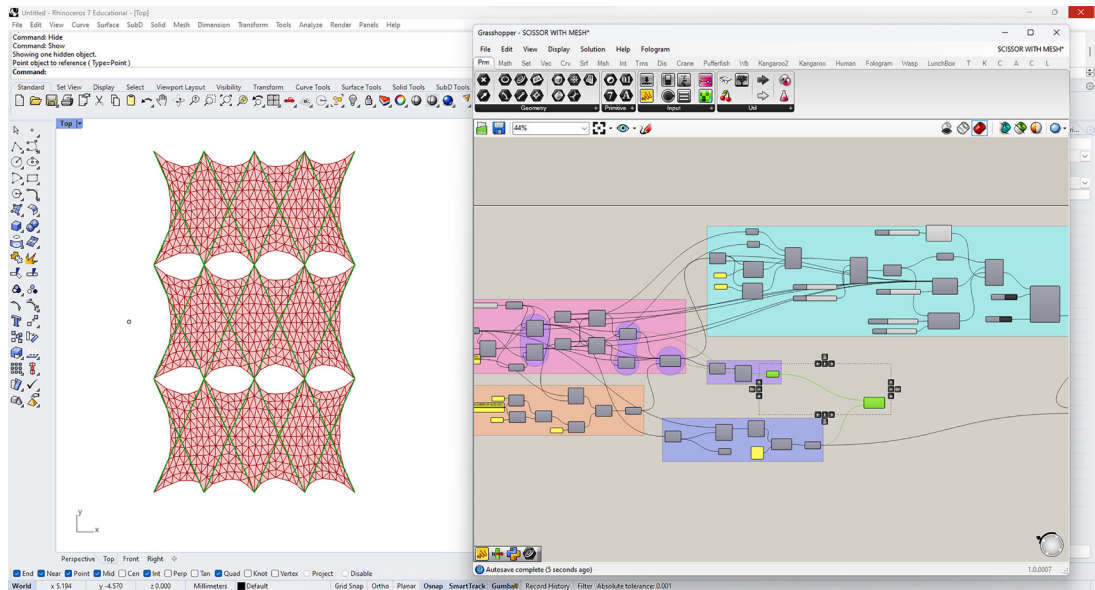
The iterative process of designing, simulating and fabricating allowed for continuous refinement, ensuring that the final knitted panels met the necessary specifications for size, shape and elastic performance. The digital process ensured that the dynamic qualities of the knit materials, such as their ability to stretch, warp and change under tension, were controlled in such a way that would balance the materials' elasticity and different directions.

This development in knitting is new, since many of the precedents and much of the research being conducted by Mette Ramsgaard Thomsen, Jenny Sabin and others only address knit materials for their digital fabrication, tensile performance or aesthetic qualities. This research is novel because

it utilised the material's elasticity as an active participant in the design's movement.

The two resulting wall designs explored different orientations and alignments of attaching the knit panels within the scissor grid structures, each resulting in unique interactions between the material and the framework. The first design focused on grid and panel alignment, while the second experimented with a crossing orientation. Both designs demonstrated how digital tooling can control the dynamic properties of knit materials, resulting in a controlled yet expressive architectural element. Ultimately, the success of these designs lies in the seamless digital and physical design workflow. The precision offered by the digital tools used ensured that the dynamic properties of the knit textiles were effectively managed, creating a balance between flexibility and stability. This project exemplifies how digital design and fabrication can aid in material and pattern development for knitted designs when it is necessary to predict various outcomes for the proposed materials.

The results of this research address larger discussions of dynamic architectural elements. Furthering the ideas by Yona Friedman, Cedric Price and others. By proposing new potential uses for scissor mechanisms to provide more architectural uses as good transformable devices, which previously lacked surface materiality that could be used to create enclosure and barrier. The dynamic outcomes of this project emphasise how material patterning can exaggerate movement and material properties, creating a visual expression of forces and tension and providing more opportunities to use scissor mechanisms in architectural applications. These designs could find uses as deployable division walls to quickly reconfigure and adapt architectural spaces for different uses and needs. In addition, they could provide opportunities for façade panels to respond and adapt to environmental stimuli. The possibilities for these flexible panels prove to be a test case for further applications.

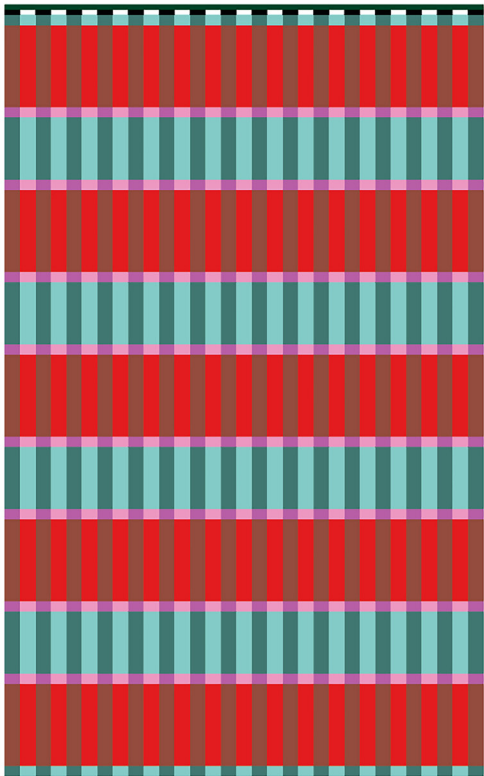
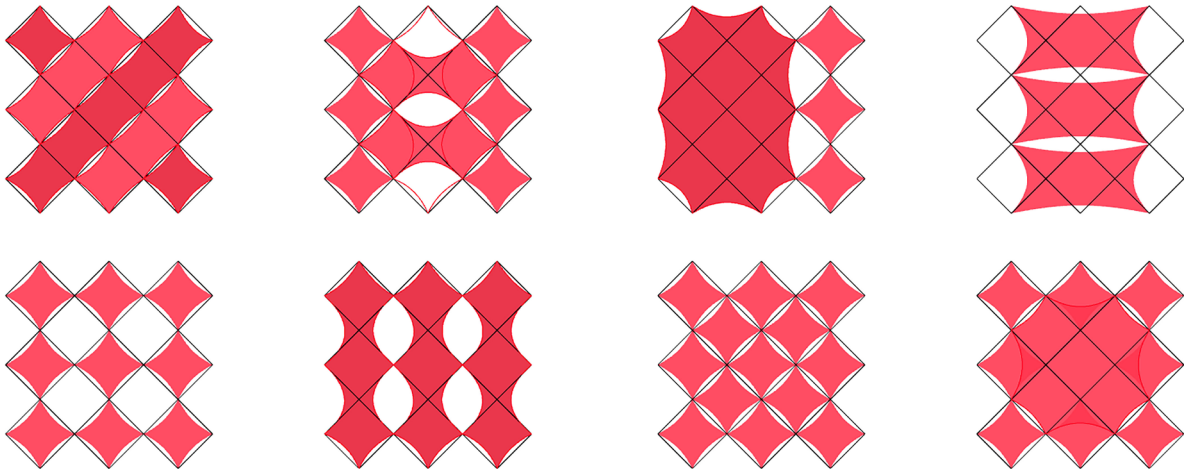











**Figure 1 (top).** Samples of small-scale scissor designs with various knit materials. *Source: Author.*

**Figure 3 (next page, top).** Different design panel arrangements. *Source: Author.*

**Figure 2 (bottom).** Scissor structure simulation combined with mesh in Grasshopper and Kangaroo. *Source: Author.*

**Figure 4 (next page, bottom).** Example pixel pattern for rib knit elastic stripes and key. *Source: Author.*

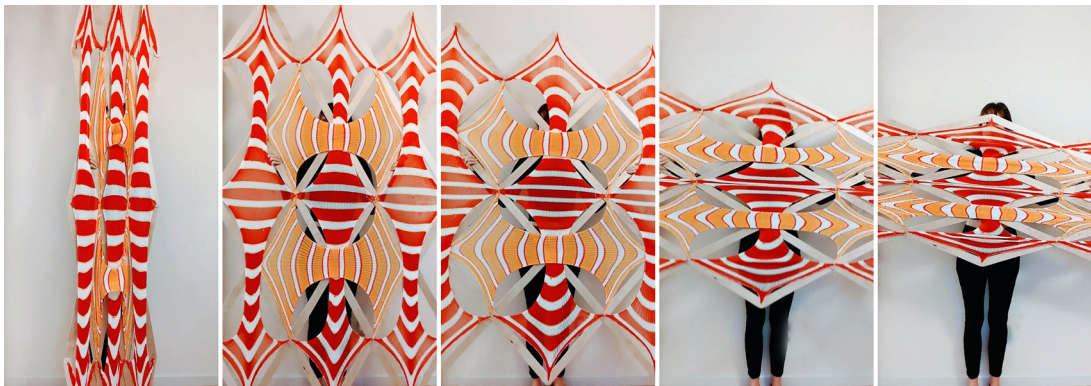


	NO ACTION		BIND OFF Rear Bed
			TRANSFER Rear
	NYLON FIRST COLOR FRONT		NYLON FIRST COLOR REAR
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	ELASTIC SECOND COLOR FRONT		ELASTIC SECOND COLOR REAR



**Figure 5 (this page and next).** *Different states of deployment of the diagonal design scissor grid.*





**Figure 6 (top).** Final arrangement of the orthogonal design knit panels. *Source: Author.*

**Figure 7 (bottom).** Movement of the front orthogonal panel. *Source: Author.*

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## Bio

**Virginia Ellyn Melnyk** is a designer, researcher, and educator whose work explores the intersection of digital design, material innovation, and adaptive architecture. Her practice integrates computational design with hands-on making, focusing on transformable structures and the use of knitted textiles within architectural applications. Virginia holds degrees in architecture from the University of Pennsylvania and the University at Buffalo and is currently completing her PhD in architecture, investigating knitted membranes for deployable structures. Her work has been exhibited internationally and has received many awards. As an educator, Virginia has taught across design studios and digital fabrication courses, at universities such as University at Buffalo, Clemson University, Virginia Tech, and currently at Iowa State University. Her research and practice aims to advance sustainable, adaptive design methodologies, emphasizing tactility, interaction, and the environmental potential of lightweight, transformable systems in architecture. Virginia envisions a future where architecture adapts seamlessly to meet changing needs and conditions.