SHRINK FILM ARCHITECTURE

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Abstract. This paper is about designing a process to create a light-weight building envelope using a shrink-film. The advantage of using this material for architecture is that we can simply construct the complex geometry without requiring an expensive formwork. In addition to this, this research illustrates the methodology to control the 3-dimensional form of the shrink-film by using simple 2-dimensional patterns. These patterns enable us to easily manipulate the form. In this paper, the simulation and the prototyping are conducted in both physical and computational methods.

Keywords. Material Computation; responsive material; form-finding.

1. Introduction

The main objective of this research is about design methodologies and a manufacturing process for generating complex geometries, and their potential application in architecture. Through this research, the author would like to maximize the possibility of the material’s inherent visual properties and structural applications by testing physical models and computational simulations. The paper focuses on shrink-film, which is primarily used as a packaging material, to create a light-weight building envelope. Shrink-film is a responsive material. It can be shrunk with the application of heat, and tightened to secure its content.

In the traditional building industry, constructing a 3-dimensionally curved form requires significant time, and therefore it becomes costly to manufacture. The advantage of using shrink-film for architecture is that we can simply construct the complex geometry without requiring expensive formwork. This method of construction is highly integrated with the design and the structure.
2. Material

2.1. PRIMARY USAGE

Basically known as a packaging material, shrink-film can be shrunken by applying heat. It is used for wrapping small products as well as covering ships or helicopters, at a larger scale. In the industry, several types of shrink-film are produced, and they differ in their ingredients, size, thickness, shrinkage coefficients, heating temperature, rigidities and so on. To utilise this material for the tension member of the building envelope, it is important that the film needs to be rigid after shrinking. For this reason, the author chose the type of shrink-film that is usually used for the labels of plastic bottles. This material can be shrunk below a temperature of 100°C, such that the shrinking is capable by hair dryer.

2.2. BASIC PRINCIPLE

This research proposes the two different ways to realise "Shrink Film Architecture". These two have different types of 2D patterns and compressive materials.

One type is called "Circle Packing" which has the different sizes of circular compressive material. These circles pack the surface of shrink-film. Once the heat is applied to the film by dryer, the film between circle and circle is shrunken; neighboring circles are connected each other and structurally hold the form. This means the final form can be determined by the 2D layout of these circles.

Another is called "Flexible Wire". Its compressive material is a piano wire that is a flexible and corded material. The main difference between this method and "Circle Packing" is that the geometry of compressive material is also changed because of the flexibility of the piano wire. So, while the film shrinks, the wire is also deformed. As a result, the combination of these two materials can create the particular geometry locally and globally.

Each methodology is tested and simulated by physical modeling and computational simulation. As a result, two different possible architectural applications are proposed according to properties of these methods.

3. Circle Packing

3.1. PHYSICAL PROTOTYPING

To understand the relationship between the circular components and shrink-film, a series of the model studies were conducted. The outline of the model is generally divided into the centre part and the legs which touch the ground.
First, the circles, which are made out of cardboard or foam board, pack the shrink-film and they are connected each other by glue. An additional elastic wooden stick is attached to the base to support the geometry. Second, heat is applied to the shrink-film with the model hung upside down. Once the film is completely shrunken, the film keeps the circles connected, creates the geometry, and holds the dome structure. This test was repeated with different outlines, ranging from three legs to five legs, and patterns with varying densities.

![Figure 1. Physical model studies with shrink-film and different circular components.](image)

3.2. COMPUTATIONAL SIMULATION

3.2.1. 2D Pattern Generation

From the understanding of physical prototyping, a 2D pattern is generated by computational simulation tool Grasshopper, which is a plug-in for Rhinoceros, a stand-alone 3D modeling software. It can pack the surface with circles, the sizes of which can be gradually differentiated using the software. For example, the leg regions have smaller circles than the other areas, because this part becomes more curved in 3D. Correspondingly, the top part has bigger circles, because this part become relatively flat and should be structurally lightweight.

In addition to this, the software differentiates 12 different sizes of circle for simplifying the fabrication process, indicated in different colours in the diagram below.
3.2.2. 3D Form Simulation

Based on the 2D pattern which is generated in the previous chapter, the 3D form is simulated by Kangaroo, a live physics engine that lets users perform physics simulations in Grasshopper. The geometry of the circles are created by mesh, and the connected of circles act as springs in the 3D model. The application of the gravity "relaxes" the geometry. Because of it, the 2D pattern changes into a particular 3D form. This 3D relaxation process and 2D pattern generation process interact with each other. Once the 2D pattern is changed, the 3D form simulation can check the result of a new 2D pattern. Likewise, the feedback of 3D form can affect the next 2D pattern. The author arrived at the prototypical geometry by repeating these interactions.

3.3. FABRICATION FOR THE PAVILION

3.3.1. Detail

At full scale, the circles need to be rigid, lightweight, and easily manufactured. For these reasons, laminated bamboo was selected as a material for the
circles instead of cardboard or foam board. The film is inserted into two layers of bamboo, with the inner rings two times thinner than the outer rings. The friction between the two rings and the film makes the rings stay in the same position while the film is shrinking without any glue. This configuration allows the film on the outside of the rings to work as a tension membrane, and on the inside of the rings the film keeps the geometry, much like the spokes of a wheel.

3.3.2. Construction

In construction, the rings are arranged based on a full-scale print of the diagram. After attaching the rings, the entire geometry needs a shallow initial curvature, and the heat is applied to the film by dryer for shrinking. While applying the heat, the top part of the curvature is gradually moved higher into the ideal (final) curvature. After completing the shrinking process, the bases are connected to the five legs of the pavilion and fixed into position. This pavilion was sufficiently big and could create a space of unique and dynamic quality. Although the process still needs a lot of human labor for now, the principle of the construction is simple. Therefore, the fabrication process can be alternated by robotic technology. For instance, the heating process by robotic arm has potential for improving the precision and speeding up the process.

Figure 4. Full-scale prototype. The flat sheet becomes a 3D form by applying heat.
4. Flexible Wire

4.1. PHYSICAL PROTOTYPING

4.1.1. Form Changes in Local Conditions

Based on the method of "Circle Packing", another architectural possibility of the shrink-film is investigated in a different way, without the use of rigid fragmented components.

The second method uses flexible wire to control the behaviour of shrink-film. Throughout the experimentation process, piano wire is attached to the film with transparent tape. While shrinking the film, the wire also deforms. As a result, the surface develops an organic form. But, if the pattern is a simple grid, the wire randomly deforms according to the order of applied heat. However, if attaching the wire in a woven pattern, it could regularly deform and create an organic surface. This is because the weaving pattern makes two different types of points in a sheet: wire crossing-points and wire touching-points.

![Figure 5. Model studies with wires. The woven pattern (right) makes regular deformations.](image)

4.1.2. Form Changes in Global Conditions

In the previous chapter, the experiment shows a global flat surface with local deformations by the weaving wire pattern. To control the global geometry, the density of this pattern is differentiated. This is because the global curvature is corresponding to the area of film that is surrounded by wires. To create a dome shape, the periphery of a sheet has the bigger area and the centre has the smaller area. The resulting deformation of the periphery is bigger and the centre one is smaller, and it globally becomes dome-shaped. This paper proposes three different types of density changes. In pattern A, denser regions work as "ridges" of the dome. In B, the areas with denser spacing be-
come the "peaks" (small domes). In C, a radially differentiated pattern makes the highest dome in these types.

![Figure 6. Global form studies with different patterns. They have different densities.](image)

4.2. COMPUTATIONAL SIMULATION

4.2.1. 3D Form Simulation

The transformation of form by shrinking is simulated by Rhinoceros, Grasshopper, and Kangaroo, similar to the "Circle Packing" example. This time, the film is created by a series of meshes that can be shrunk by a certain amount. The pattern of piano wire is simulated by polyline springs that have fixed length. And in order to simulate flexible bending resistance of piano wire, the angles defined by the polylines needs to be controlled. The difference between physical and computational modeling lies in the connection of film and wire. In the computation, the film is divided into segmented meshes, and these meshes are connected by the polyline springs that represent piano wire. The result of the computational simulation can show not only the particular geometry changes, but also the behaviour of shrinking, corresponding to the physical prototyping of actual shrink-film and piano wire. It enables us to simulate a larger scale of model or complex differentiated patterns. With this potential 3D geometry, a structural analysis can also be tested.
4.2.2. Structural Simulation

The structural properties of basic forms are simulated by FEM (finite element method). First, the curve of piano wire and the film are simplified into line segments and mesh. In addition, the material properties of wire and film such as strength and size are also applied to each segment. To simulate the global change of form, each crossing point of a segment is raised step by step, until a dome shape with local regular deformation of its surface is generated. The colour of the segment shows the extent of structural risk or failure. Comparing the first and the final geometry, the final one has fewer segments at risk, shown in red, than in the first one. This means that geometry that has local deformations can become more stable when the form is globally changed into a dome shape.

4.3. ARCHITECTURAL APPLICATION

Ultimately, the integration of physical material analysis, physical prototyping, and computational simulation allows for architectural applications. In the actual building scale, the piano wire needs to be replaced by thicker steel or fibre composite to support the structure as a compressive member. This structure does not require footholds or cranes for construction. Even the frame of an additional structure, which most membrane structures have already, is not necessary. Basically, once the wire is attached to the film in the prefabrication process, the construction on site requires only applying heat to shrink the film. In this method, one sheet of membrane consists of a com-
combined tensile surface and elastic compressive members. Although this proposal is not realized yet, it shows not only the potential for an architectural application of shrink-film but also the possibility of a new type of membrane structure. Further research can focus on fabrication of pavilion scale prototypes by integrating added technological aspects, such as improvement of the film durability or the connections between the film and wire.

Figure 9. Architectural application of "Flexible Wire" method. This is a pavilion proposal.

5. Conclusion

As a result of methodical research that includes material analysis, physical prototyping and computational simulation, complex and particular geometry is made possible by the properties of shrink-film. The two applications of shrink-film architecture create the spatial quality of domestic environments by maximizing the material’s inherent properties, both visually and structurally.

This paper also enhanced the potential of "Form-finding" as an architectural generative method even today. In the beginning, the research started from the physical experiment by models, similar to those by Frei Otto. However, by using computational technologies, the author simulated the material behavior and analysed the structure. Ultimately, the combination of physical experiments and computational simulations achieved intricate design systems that define global form by local manipulations. Although the two investigated methods begin with different initial components (circles and wires) and result in different generated geometry, both of them succeeded in controlling geometry by differentiation of 2D patterns.

Although the "Circle Packing" methodology can realise an actual pavilion, the system still does not address real building concerns such as air insulation or durability of material. And, in order to scale up the pavilion, the construction needs to be engaged in digital fabrication, for example robotic assembly instead of reliance on human labour. The system of "Flexible Wire" still has
the question of the connection between the film and the piano wire, which should be improved at full scale. For the two methodologies, most of the main problems require collaboration with additional technology or knowledge of other professions. Further interdisciplinary research will start to address the application to a more detailed, actual building envelope.

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References