Spulenkorb : Utilize Weaving Methods in Architectural Design

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Abstract

We introduce weaving as an alternative approach to construct the skin of an object. To demonstrate the possibility of the approach, we have designed a digital fabrication project, called *Spulenkorb*. The project received an honorable mention in the Texfab competition November 2010 [1]. The initial form is conceived as a ribbon that twists and returns on itself. The base mesh of the initial form is developed using *TopMod3D* and *Maya*. We then converted the base mesh to a model of the woven object using the weaving software we have developed.

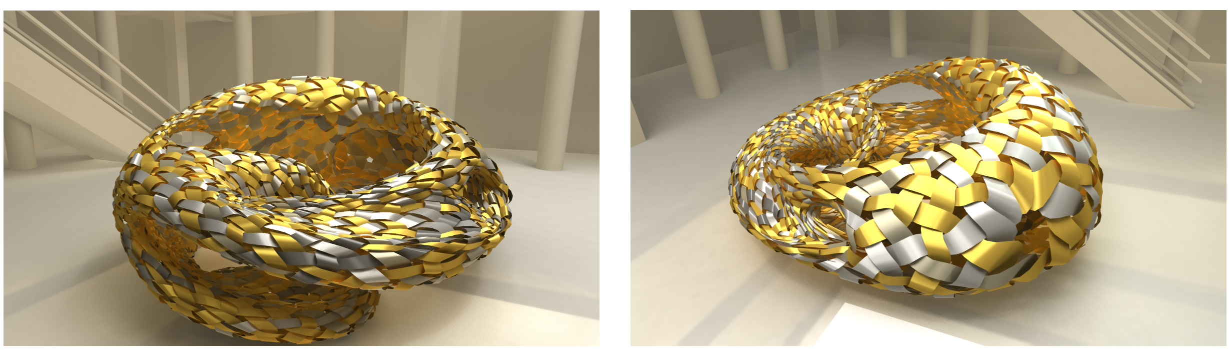


Figure 1: *Spulenkorb fabrication design showing irregular weaving patterns based on pentagonal subdivision geometry.*

1 Introduction

Knots and links are interesting structures that are widely used for tying objects together and for creating beautiful shapes such as woven baskets. To topologists, a knot is a 3D embedding of a circle and a link is a 3D embedding of more than one circle. We prefer to use the general term *link*, since each component of a link is also a knot. Mathematical links can be used to represent weaving structures such as a fabric, a cloth, or a basket. There exist a wide variety of weaving methods. Among them, the most popular is *plain-weaving*, which consists of threads that are interlaced so that a traversal of each thread alternately goes over and under the other threads (or itself) as it crosses them.

Beyond its use in fabric design, weaving provides a wide variety of ways to create surface patterns that can be embodied in sculpture and in innovative architectural design. It has recently been shown [3] how any given polygonal mesh can be transformed into objects woven from ribbons of varying width, such that the ribbons cover the underlying surface almost completely, except for small holes. The ribbons can be manufactured inexpensively by using a laser-cutter on thin metal sheets. The corresponding plain-woven sculptures are constructed physically by weaving these metal ribbons. The sculptor James Mallos has recently constructed a large triaxial woven sculpture of a fingertip [10], using a Mercat type algorithm [11] on a manifold mesh surface with a boundary. There exists a contemporary interest among architects to explore weaving as an alternative construction method [9, 7] based on traditional bamboo-woven housing [8, 12]. This suggests how weaving with ribbons from thin metal sheets can also be useful for economical construction of complicated shapes.

In this work, we present *Spulenkorb*. See Figure 1, which is a plain woven digital fabrication project. The initial form was conceived as a Moebius rind. Figure 2 shows the basic geometry that we developed in *Maya*. We then continued to tessellate the mesh in *TopMod3D* to include vortex apertures and variable, ornamental perforations, shown in Figure 3, in an effort to test the robustness of the weaving algorithm. We are currently developing software to help easy construction of woven objects such as *Spulenkorb*. The software outputs the unfolded geometry of the long weaving cycles and breaks them into short segments. The segments are joined by flaps in construction.

2 Motivation

There is a vast precedent in fabrication projects that deal with the idea of weaving, however within those projects there are more specific techniques. This project concerns itself specifically on the spiral or coil. In [5] Aranda/Lasch describe this technique “the spiral (which) is not so much the shape as the evidence of a shape in formation”. This idea implies constant movement as a desired effect - something architecture has historically aspired to. Aranda/Lasch continue the argument in terms of spiral lattices as multiple woven points that weaving produces stability. This gives the potential of using the technique as a waytoassurethestructureoftheproject’sform.To employ such a technique, one would have to use materials and tools that provide a ribboning or weaving methodology.

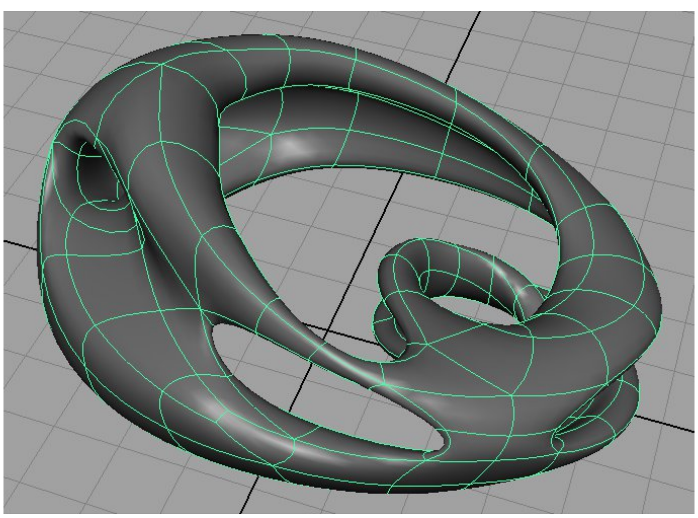


Figure 2: *Initial surface in* Maya.

When we began to research more about weaving techniques, we looked at “coiled”and “plaited” basketry. Baskets are categorized by technique. We found diagonally plaited baskets produce a more contemporary effect. At the same time, coiled baskets provide more stability in that they employ a technique of bundling strands or rods stitched into a spiraling oval or round form with a thin, flexible element to create a coil. Numerous variations of stitch types and embellishments (such as imbrications) can afford a wide range of possibilities.

Spulenkorb is a combination of both techniques. The word *Spulenkorb* literally means a coiled or spiral-form basket. The interest in a coil-spiral-weaving technique is the idea of movement - a propelling force that makes things operate - a pattern and certain geometries referential to physics and chemistry as well as in popular culture, music, and film - all while being sensitive to architectural logic of elegance in structure and form. This project was awarded an honorable mention in the "REPEAT" competition organized by TexFab November 2010[1].

3 Surface Design

We use *Maya* to design the initial base object of *Spulenkorb* (See Figure 2). *Maya* is an application used to generate 3D assets for use in film, television, game development and architecture. More information can be found from the product web page [6].

For further changes in the design of *Spulenkorb*, we extensively used *TopMod3D*, which is a topologically robust polygonal modeler that is developed by the research group led by Ergun Akleman [2]. The initial version of software, *TopMod3D 1.0*, has been available as free software since 2003. Since then, a set of talented artists discovered the system and created very interesting sculptures. In August 2007, a new version, *TopMod3D 2.0*, with an improved user interface and scripting editor was released. This version runs on *Mac*, *Linux* and *Windows* platforms.

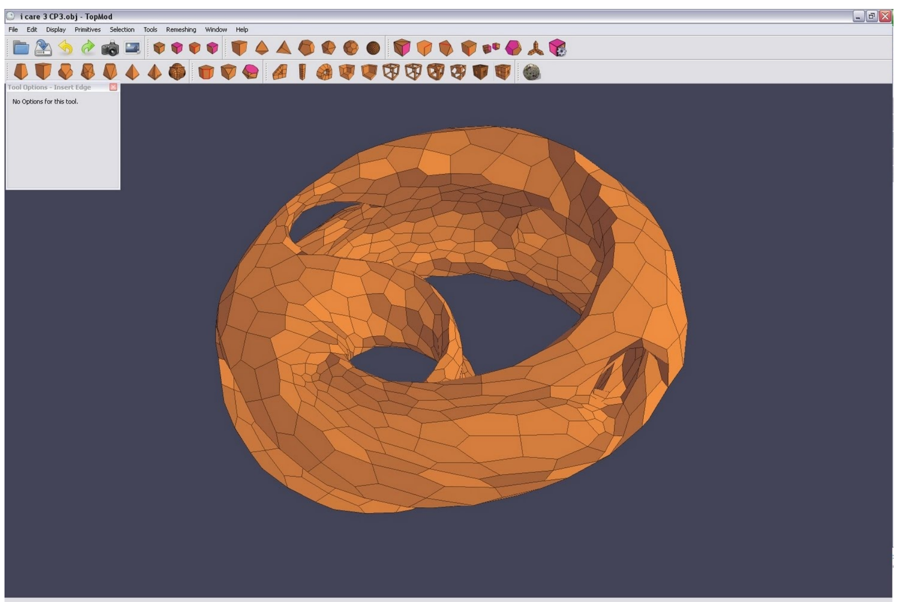
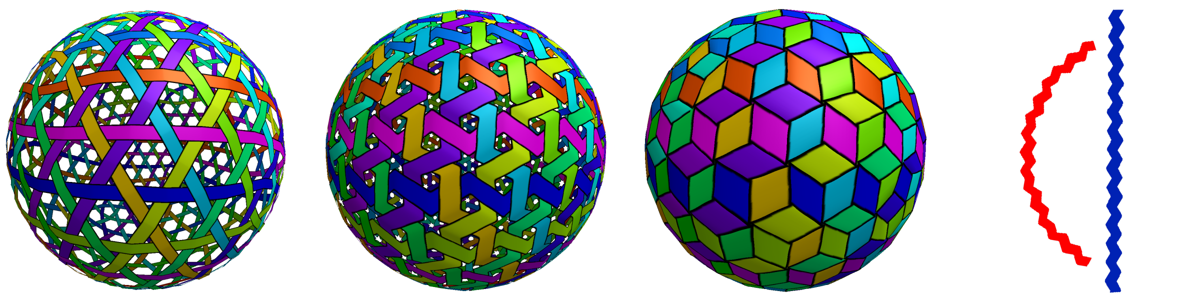


Figure 3: *The resulting mesh after applying the pentagonal subdivision to the initial coil mesh in* TopMod3D.

The main achievement with this modeling system is the development of new ways and tools to design polygonal meshes with huge number of handles, holes and columns, i.e., very high genus 2-manifold meshes. It is a very dynamic and growing system. Its underlying data structure and minimal set of operations help to develop simple algorithms and guarantees to have 2-manifold property of meshes. The current version of the system already includes a wide variety of tools that provide a large number of ways to manipulate 2-manifold polygonal meshes. The system is compatible with commercial modeling systems i.e. the models created in this system are portable, and can be manipulated in other systems like *Maya*. It is also easy to construct very complicated watertight shapes that can directly be built using rapid prototyping machines. Figure 3 shows the design of *Spulenkorb* in *TopMod3D*.

One of the reasons behind the popularity of *TopMod3D* is that it has a very easy learning curve. The designers in our team used less than one day to learn the interface and operations. Though the most important differentiating feature of the system is the robust and easy modeling of very high genus manifold meshes, the system has many additional features which complement the high genus modeling tools. For instance, it provides a wide variety of remeshing tools which can be applied to polygonal manifolds. Using these tools, all semi-regular mesh structures can be created. This provides us a rich pool of base meshes that can be used to generate different weaving patterns in our project. The pentagonal subdivision [4] was particularly useful for our project. This subdivision scheme can create a pentagonal mesh from any arbitrary mesh. We use the pentagonal subdivision to obtain a base surface to create the final form of plain woven *Spulenkorb* (see Figure 3).

4 Plain Woven Object Conversion



(a) Sparse Weaving (b) Dense Weaving (c) Very Dense Weaving (d) Unfolded Wavy Ribbons

Figure 4: *(a) The projection method can create the same type of "sparse" weaving, by leaving gaps as shown. (b) Using the projection method, we can also create dense triaxial weaving on any regular triangular mesh, as shown. (c) The wavy ribbons cover the whole surface almost without gaps. (d) This particular mesh consists of 18 cycles of ribbons. Unfolded versions of these ribbons show that the ribbons are wavy and that there are only two types used. The construction requires 12 from the circular-type ribbon (left) and 6 from the straight-type ribbon (right).*

To covert this surface to a plain woven object we have used a system that is based on a theoretical approach by Akleman et al. [3] (See Figure 7). This theoretical approach is used to create plain-weaving structures based on graph rotation systems. With the graph rotation system structures, it has been formally demonstrated that by twisting a subset of edges of an orientable manifold mesh, one can obtain an alternating link, which is the mathematical model for a plain-weaving. Based on this result, it is possible to convert a link projection on a polygonal surface to a plain-woven object. Figure 4 show "sparse"and "dense" weaving that can be obtained with this method [3]. It can be seen that the "sparse" weaving strongly resembles familiar woven-basket structures, which are created using bendable but straight yarns. These structures can leave large gaps in some weaving patterns. By adjusting parameters in the weaving program, the user can control the size of the gaps, so that one can obtain "dense" weaving. With "dense" weaving, the original manifold surface can be covered almost without gaps using ribbons whose unfolded versions are wavy as shown in Figure 4(d). For our project, we choose to use a relatively "dense" weaving.

The system we have used can convert any manifold mesh to a plain-woven object. The shapes of the threads can be interactively controlled with a set of parameters. The system provides two types of flavors for 3D thread structures, ribbon and tube. Figure 5 shows all eight cycles of the *Bunny* model in the tube form. The structure of underlying mesh defines the overall look of final woven objects as shown in Figure 4. The

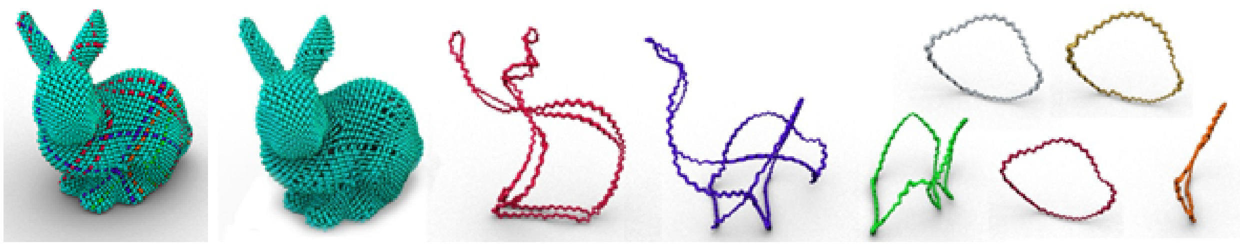
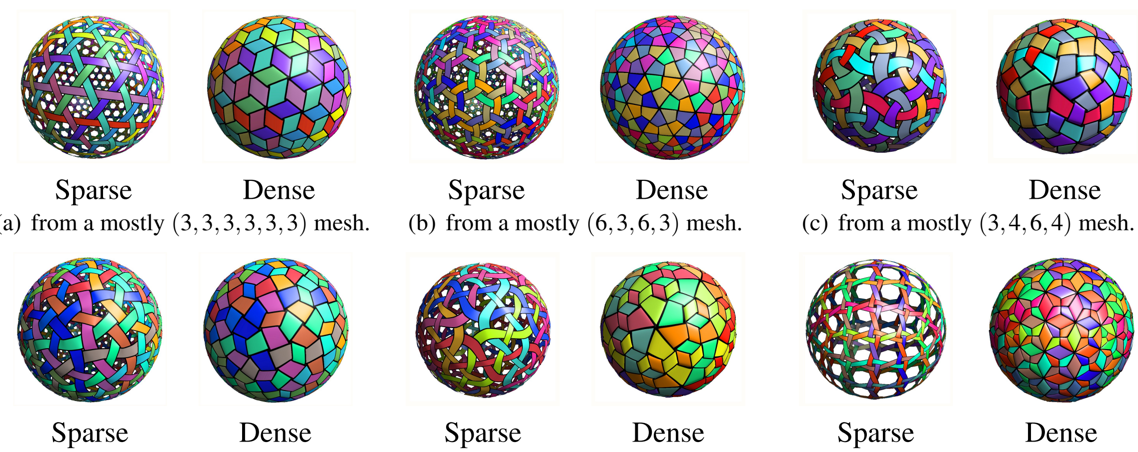


Figure 5: *These images show the whole woven object and all eight cycles (threads) of the* Bunny *model.*

notation $(m_0, m_1, ..., m_n)$ refers semi-regular structures where most faces have n sides and vertex valences are $m_0, m_1, ..., m_n$ in a cyclical order. As it can be seen in Figure 4, weaving from $(3,3,3,3,3,3)$ meshes can look significantly different from weaving from, say, $(6,3,6,3)$ meshes. Since we obtained our initial model using the pentagonal subdivision over a quad mesh, our polygonal mesh consists of mostly $(3,3,4,3,4)$ (see [3] for detailed discussion.). An example of such pattern is shown in Figure 6(d).



(a) from a mostly $(3,3,3,3,3,3)$ mesh. (b) from a mostly $(6,3,6,3)$ mesh. (c) from a mostly $(3,4,6,4)$ mesh.

(d) from a mostly $(3,3,4,3,4)$ mesh. (e) from a mostly $(3,3,3,3,6)$ mesh. (f) from a mostly $(4,8,8)$ mesh.

Figure 6: *Examples of weaving patters obtained from mostly regular and semi-regular meshes. The Figures 6(a) and 6(b) show two semi-regular weaving patterns. The rest of the patterns are not semi-regular.*

Once the basic geometry was developed, we experimented with a series of subdivision routines to help determine which might provide the type of weaving that we ultimately desired. The Figure 2 shows the initial mesh for the plain woven object. Our team finally selected the pentagonal subdivision [4] because of the flower-like aperture treatment and the relationship between the various ribbons. Figure 7 shows the weaving ribbon pattern. Different ribbon cycles are colored differently.

There was also a strong necessity of the final algorithm: weaving the mesh based knots and links. These links can be represented in various ways, and can be passed through a subdivision-extrusion-reevaluation procedure to produce the desired woven effect. The weaving program exports the weaving geometry in .obj files which are further processed by *Maya*, as shown in Figure 8.

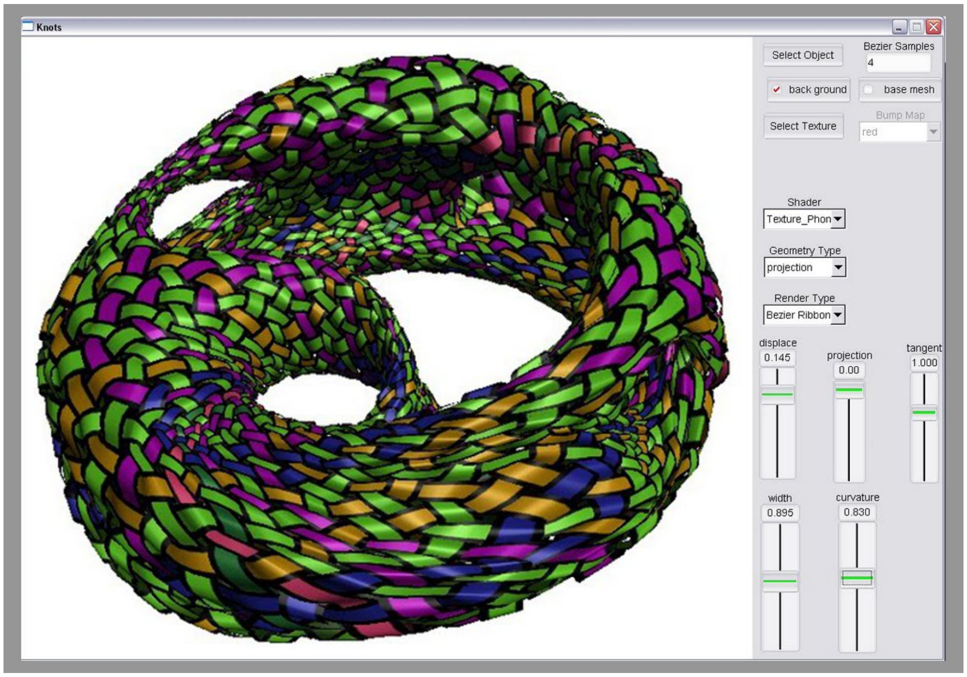


Figure 7: *Weaving program screen-shot. The sliders control the width of the ribbons, size of gaps, and how tight the weaving ribbons conform to the base object.*

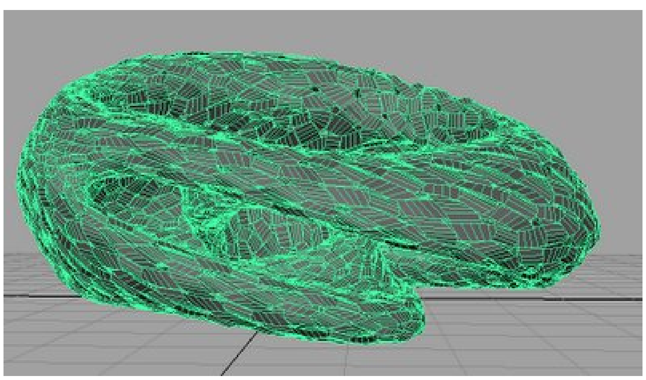


Figure 8: *Weaving geometry in* Maya*.*

The final state of the project includes a series of six continuous ribbons of various lengths. Additionally, none of the ribbons are straight, nor do they maintain their width. These variables are determined by the geometry, the algorithm, and the further parametric variables provided in the weaving algorithm. Each ribbon includes several hundred developable surfaces, each with a unique four-sided condition. See Figure 9. It is because of these specificities, and because of the recent development of the tools that such a project can be conceived, digitally or otherwise.

5 Conclusions and Future Work

In conclusion, up to this point much of the current parametric fabrication projects focus mainly on surface operations, like tessellation. Our project utilizes new parametric solutions and challenges through the use of emerging tools (such as *TopMod3D*) and algorithms (such as cubic pentagonalization and weaving theory and technique). Therefore, *Spulenkorb* provides a distinct relationship between form and system, not only as structure, but also in terms of aperture, geometry, and effectual space, all provided through geometric research and the parametric algorithm.

The geometry of weaving is an extremely interesting topic. The transportation of weaving into the realm of architectural tectonics and materiality is even more interesting. Our next research stage is to build this

(a) Phase One
Isolate the ribbon

(b) Phase Two
Unroll ribbon as developable surface
Divide for fabrication layout

(c) Phase Three
Layout CNC template
from previous divisions

Figure 9: *One of six "irregularly" shaped ribbons unrolled onto a flat surface.*

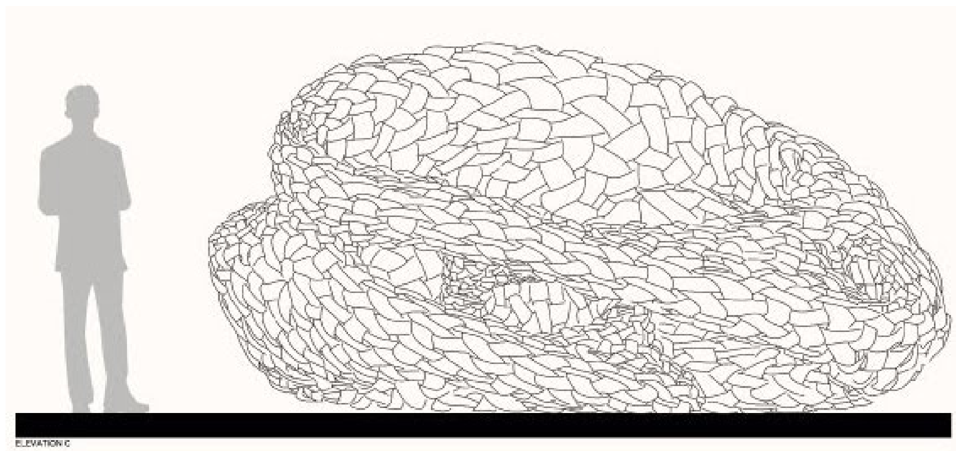


Figure 10: *Scale of the woven object.*

woven object as an architecture building envelope. Figure 10 shows the size of the object related to a human. Figure 11 gives us a feeling of standing inside the woven enclosure.

There are many practical issues for us to address in the future research. First, it is not easy to take fabrication techniques that work at one scale and apply them at another scale as there are numerous problems with the scale shift. Second, the unrolled flat strip is crazy in regards to almost every flat-sheet fabrication method. It is highly inefficient and might create a huge amount of waste of material. Third, the strips would be so long and cumbersome that the actual weaving would be very difficult for the construction of such a structure. We might explore ways that the strips could be shortened into more manageable lengths as it would make it much more interesting and a good evolution of the idea of weaving in architecture.

Since the design of *Spulenkorb*, we have been researching on the material and constructing technicalities of irregular weaving on an architectural scale. We started with small scale objects by using different materials. We found that the PVC laminate called *Sintra* offers great bending property. Our next research focus is to solve the various technical challenges of building the object in full scale.

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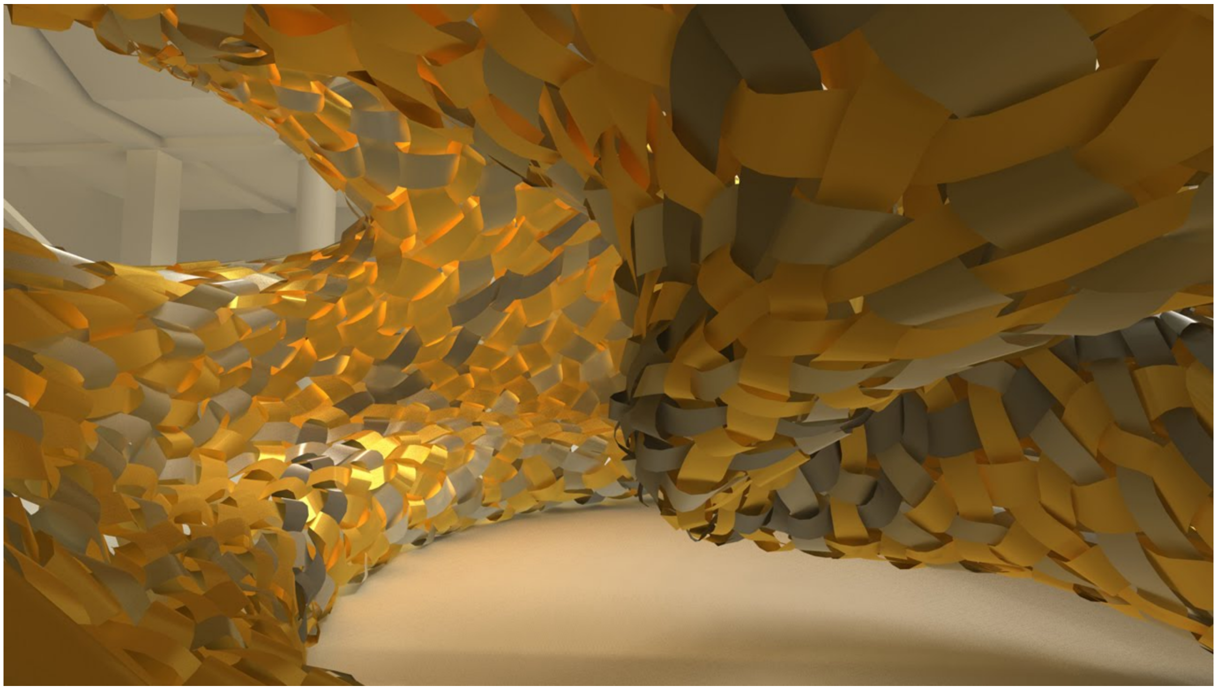

Figure 11: *Woven enclosure.*

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