

# Weaving Methods in Architectural Design

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## Abstract

In an effort to investigate surface logics consisting of highly porous, irregularly defined weaving systems a series of investigative strategies were employed. This paper discusses certain modes of research and their derivatives through a case study, Spülenkorb, as an entry into a digital fabrication competition by Texfab, in which the project received honorable mention. The initial form is conceived as a Möbius band, a geometrical variant of the pure mathematical “strip”. The base mesh of the initial form is developed using the software TopMod3D and Maya. This base mesh is then processed into a woven object using internally developed weaving software.

Knots and links are interesting structures that are widely used for tying objects together and for creating interesting 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. While there are a wide variety of weaving methods, 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.

## Introduction

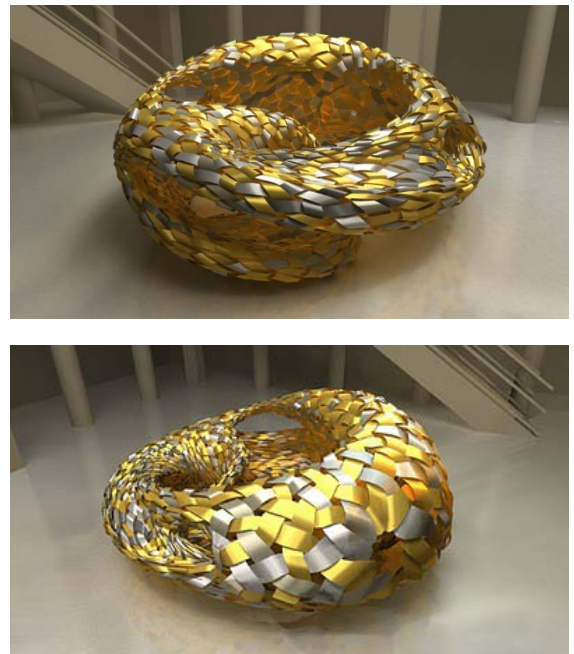
Beyond its use in fabric design, weaving provides a wide variety of ways to create surface patterns that can be embodied in sculpture and in innovative architectural design. It has recently been shown [2] how any given polygonal mesh can be transformed into objects woven from ribbons of varying width, such that the ribbons cover the underlying surface almost completely, except for small holes, as is typical in woven surfaces. The ribbons can be manufactured inexpensively using laser cutters or water jets on a variety of planer materials. The corresponding plain-woven sculptures are constructed physically by weaving the resulting ribbons. For example, the sculptor James Mallos has recently constructed a large triaxial woven sculpture of a fingertip [9], using a Mercat type algorithm on a manifold mesh surface with a boundary. In addition to sculpture, there is a strong interest among architects to explore weaving as an alternative construction method [8, 6] based on traditional bamboo-woven housing [7, 10]. However, our research suggests weaving can also be economically viable even with more complicated shapes.

The case study to be discussed is with Spülenkorb (see *Figure 1*), a plain woven digital fabrication project. The initial form was an umbilic torus – an orientable figure influenced by non-orientable Möbius strip geometry. *Figure 2* shows the basic geometry developed in Maya. The mesh then underwent a series of iterative tessellated studies in TopMod3D to study vortex apertures and variable, ornamental perforations, which was also a testament to the robustness of the weaving algorithm as shown in *Figure 3*. Software is currently being developed to streamline this process and manage construction of woven objects such as Spülenkorb.

## Sensibility

In looking at traditional weaving techniques, our team looked at “coiled” and “plaited” basketry. Baskets are categorized by technique. While diagonally plaited baskets producing a more contemporary effect, it was found that 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. Ultimately, numerous variations of stitch types and embellishments (such as imbrications) can afford a wide range of possibilities. Spülenkorb, then, is a combination of both techniques.

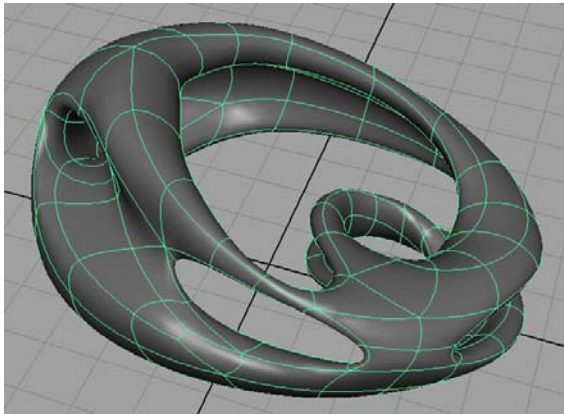
The word *spülenkorb* literally means a coiled or spiral-form basket. The interest in a coil-spiral-weaving technique is the idea of movement (a propelling force that makes things operate - often found in patterns and certain geometries referential to physics and chemistry as well as in popular culture, music, and film) while



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

maintaining sound architectural logic of elegance in structure and form as defined by the competition brief. It was through this iterative investigation and sensibility that the project yielded honorable mention in the “REPEAT” competition organized by TexFab in November 2010[11].

## Surface Design



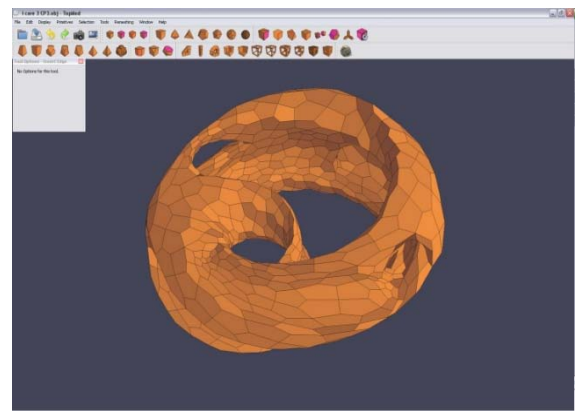
**Figure 2:** Initial surface in Maya

Maya was employed to design the initial base object of Spülenkorb (See Figure 2). Maya is an application used to generate 3D assets for use in film, television, game development, and architecture. Users define a virtual workspace (scene) to implement and edit media of a particular project. Scenes can be saved in a variety of formats, the default being .mb (Maya Binary). Maya exposes a node graph architecture. Scene elements are node-based, each node having its own attributes and customization. As a result, the visual representation of a scene is based entirely on a network of interconnecting nodes, depending on each other's information. For the convenience of viewing these networks, there is a dependency and a directed acyclic graph. More information can be found from the product web page [5].

For further changes in the design of Spülenkorb, we extensively used TopMod3D, which is a topologically robust polygonal modeler that has been developed and implemented by the research group led by Ergun

Akleman [1]. The initial version of software, TopMod3D 1.0, has been available as free software since 2003. Since conception, several artist and sculptors have employed the software to create interesting geometries. In August 2007, a new version, TopMod3D 2.0, with an improved user interface and scripting editor was released. This version also runs on Mac, Linux and Windows platforms.

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 Spülenkorb in TopMod3D.



**Figure 3:** The resultant mesh after application of the pentagonal subdivision routine to the initial coil mesh in the software program TopMod3D.



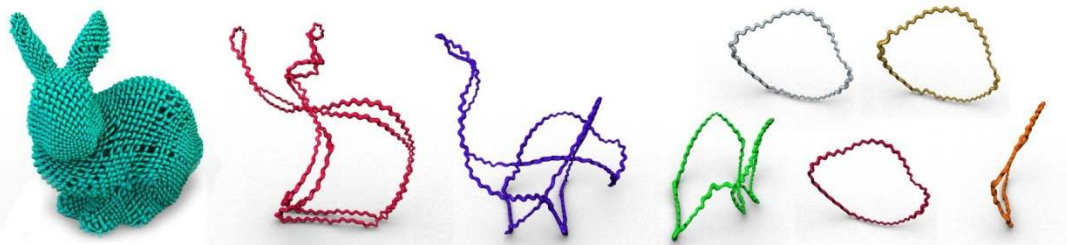
**Figure 4** (a) The projection method (PR) can create the same type of "sparse" weaving, by leaving gaps as shown. (b) Using the projection method (PR), we can also create dense triaxial weaving on any regular triangular mesh, as shown. This particular mesh consists of 18 cycles of ribbons. Unfolded versions of these ribbons show that the ribbons are wavy and that there are only two types used in (b). The construction requires 12 from the circular-type ribbon (left) and 6 from the straight-type ribbon (right).

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 both from imported geometry or geometry native to the program. This provides us a rich pool of base meshes that can be used to generate different weaving patterns in our project. While several

routines were investigated, the pentagonal subdivision [3] was particularly useful for our project because of the treatment of aperture as seen in *Figure 1*. A pentagonal subdivision scheme was applied to a base surface (see *Figure 3*) to create the final form of Spülenkorb, as shown in *Figure 1*.

### Plain Woven Object Conversion Random Text

As mentioned previously, a system based on a theoretical approach by Akleman et al. [2] (See *Figure 7*) was employed to convert a base surface to a plain woven object. This theoretical approach is used to create plain-



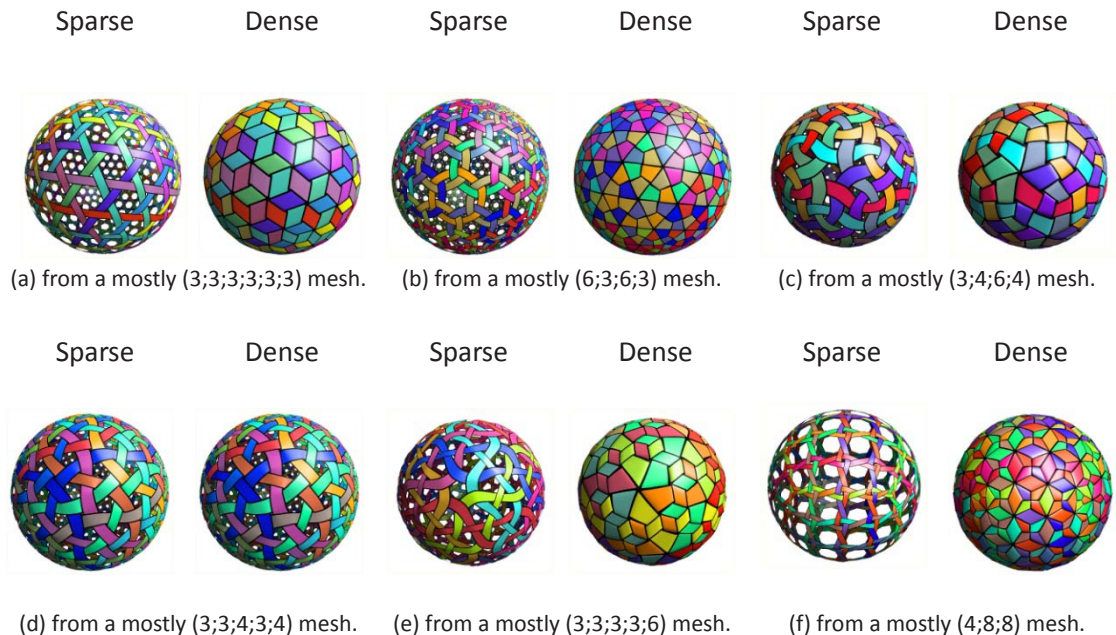
**Figure 5:** These images show all eight cycles (threads) of the bunny model

weaving structures based on graph rotation systems.

With 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* shows “sparse” and “dense” weaving conditions that can be obtained with this method [2]. 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(c)*. While parametrically controlled, Spülenkorb uniformly employs a relatively “dense” weaving pattern.

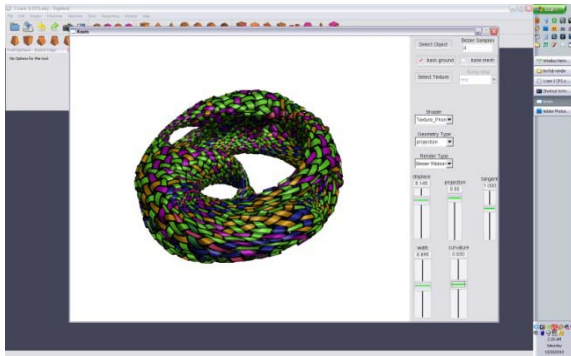
The system employed can convert any manifold mesh to a plain-woven object. The shapes of the threads can be interactively controlled with a set of parameters. The system provides two types of flavors for 3D thread structures, ribbon and tube. *Figure 5* shows all eight cycles of the Bunny model in the tube form. In the case of Spülenkorb, the structure of underlying mesh defines the overall look of final woven objects as shown in *Figures 3 and 4*. In *Figure 6*, the notation  $(m_0;m_1;\dots;mn)$  refers semi-regular structures where most faces have  $n$  sides and vertex valences are  $m_0;m_1; \dots;mn$  in a cyclical order.

As it can be seen in *Figure 6*, weaving from  $(3;3;3;3;3;3)$  meshes can look significantly different from weaving from, say,  $(6;3;6;3)$  meshes. Since Spülenkorb’s initial model used pentagonal subdivision over a quad mesh, our polygonal mesh consists of mostly  $(3;3;4;3;4)$  (see [2] for detailed discussion.). An example of such pattern is shown in *Figure 6(d)*.



**Figure 6:** Examples of weaving patterns 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.

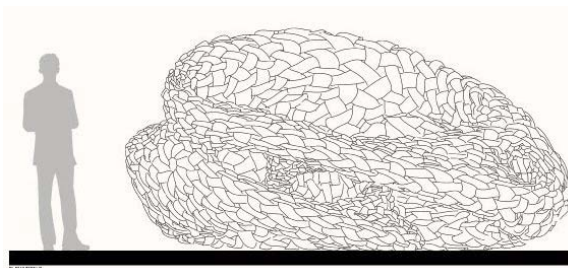




**Figure 7:** Weaving program screenshot

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. *Figure 3* shows an example of the initial plain woven objects. Our team finally selected the pentagonal subdivision [3] because of the flower-like aperture treatment and the relationship between the various ribbons. *Figure 7* shows the weaving ribbon pattern. Here various ribbon cycles are differentiated via color.

There was also strong consideration for the necessity of the final algorithm: weaving the mesh required inclusion of mesh based knots and links. These links can be represented in various ways, and can be passed through a



**Figure 8:** Scale of the woven object  
subdivision-extrusion-reevaluation procedure to produce the desired woven effect. The weaving program exports

the weaving geometry in an .obj format which can be further processed by Maya.

Spülenkorb consists of a series of six continuous ribbons of various lengths. Additionally, none of the ribbons are straight, nor do they uniformly 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, all with a unique four-sided condition as shown in *Figure 8*. It is because of these specificities, largely the algorithm and the inclusion of developable surfaces, a project can be conceived, digitally or otherwise.

## Conclusion & Future Work

Up to this point much of the study in digital fabrication research has been based on tessellated surfaces typically derived from some abbreviation of the Catmull-Clark subdivision routine, which is preference in several popular modeling softwares. Our research presents alternatives through the parametric solutions found in emerging tools (such as TopMod3D) and algorithms (such as cubic pentagonalization and weaving theory and technique), providing an opportunity to experiment in new directions. Therefore, Spülenkorb reveals 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 application and the parametric algorithm.

While the geometry of weaving is an extremely interesting topic, the transportation of weaving into the realm of architectural tectonics and materiality is even more intriguing. Our next endeavor is to study the application of weaving on a larger architectural scale. *Figure 9* shows the size of Spülenkorb related to a human. *Figure 10* gives us a feeling of standing inside the woven enclosure.

There are many practical issues to consider. First, it is difficult to take fabrication techniques that work at one



**Figure 9:** One of six “irregularly” shaped ribbons

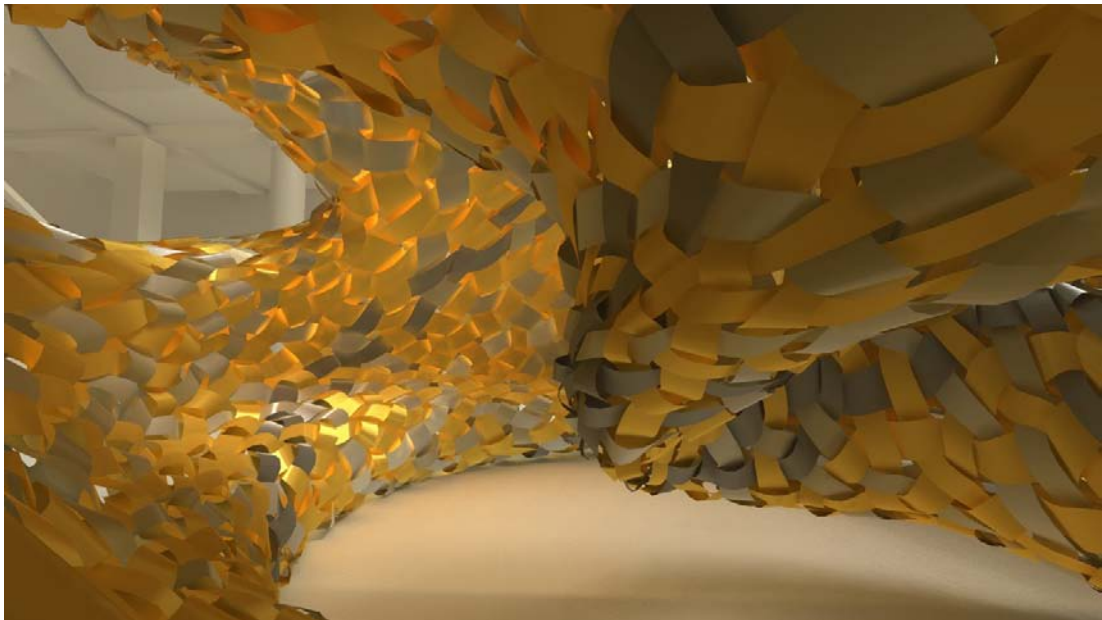
scale and apply them at another scale, as there are numerous problems with the scale shift (as with many architectural techniques). Second, the unrolled flat strip is difficult to execute in regards to almost every flat-sheet fabrication method: it is inefficient and might potentially create a huge amount of waste material. Third, the strips would be so long and cumbersome at that scale that the actual weaving might prove difficult in construction. Therefore, we propose the strips could be cut into logically directed yet shortened, manageable lengths – providing the opportunity for the design of a connection condition. Not only would it make a more interesting surface condition, but would continue to evolve our understanding of weaving in Architecture.

\Additionally, we are currently researching materiality concerns and construction techniques of irregular weaving on an architectural scale. We plan to start with small scale objects by using different materials. Once the properties of each material are deduced, our focus will shift to solving various technical challenges of fabricating the object full scale.

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**Figure 10:** Woven enclosure