Interactive Rind Modeling for Architectural Design

Ozan Önder Özener, Ergun Akleman and Vinod Srinivasan
Visualization Sciences Program, Department of Architecture, Texas A&M University, USA
http://viz.tamu.edu

The paper presents a new modeling technique for architectural design. Rind modeling provides for the easy creation of surfaces resembling peeled and punctured rinds. We show how the method's two main steps of 1) creation of a shell or crust 2) opening holes in the crust by punching or peeling can be encapsulated into a real time semi-automatic interactive algorithm. We include a number of worked examples, some by students in a special modeling workshop that demonstrate the ease with which a large variety of intricate rind shapes can be created.
Rind modeling method allows us developing a user-friendly tool for designers and architects. The new tool extends the abilities of polygonal modeling and allows designers to work on structured and consistent models for architectural design purposes. Rind modeling gives architects and designers a processing flexibility. It can be used in conceptual modeling during the early design phase. It can also be efficiently used for creating variety of shell structures for architectural design.

Keywords: *CAAD, Digital Design, 3D Modeling, Subdivision Surfaces*

Introduction

One of the interesting research areas in computer graphics is to develop new methods that provide intuitive and user-friendly modeling tools. These new methods and tools can often be utilized in architectural design process. Some of these new methods may even radically change the traditional design process by allowing designers to consider new geometries or new design experiments with expanding the solution space for design purposes.

The conceptual thinking in digital architecture has many fuzzy processes but it directly bounded to a modeling activity. This can also be assumed as a new way of electronic expression for recent values of aesthetics, form and space in the digital era of architecture. Thus modeling techniques are not only a tool; it is also the shape language to communicate in computerized media with forms and geometry. Every new algorithm and modeling technique contributes to this expanding form vocabulary.

For instance, Frank Gehry uses parametric surfaces such as NURBS to design his unusually shaped buildings. Greg Lynn can be assumed as the first designer who transformed the principles of „implicit modeling“ to the fields of design and architecture. There exist many examples from architecture, dominating the digital avant-garde era of design.

As a result different modeling techniques preferred by architects for particular design problems. Among designers NURBS modeling was generally credited with many distinct advantages over polygonal modeling. Specifically, it gives users appreciate the excellent ability to easily modify organic shapes with a minimal number of CVs while retaining a smooth surface continuity.

However, architects and designers benefited from the usage of NURBS modeling, and have success with NURBS-based form generation, the modeling with subdivision surfaces can offer all of the benefits of NURBS modeling, along with a simpler production process with the power of polygonal modeling. Subdivision surfaces also give a simpler and hierarchical model topology for transformations and modifications.

This paper introduces a recently developed computer graphics modeling method, rind modeling, for architectural design and form development purposes. Based on rind modeling method, we have developed a user-friendly tool for designers and architects. The new tool extends the abilities of „polygonal modeling“ with flexible modifiers and subdivision modeling concepts. The importance of the tool is to allow designers to work on structured and consistent models for architectural design purposes. Rind modeling gives architects and designers a processing flexibility. It can be used in conceptual modeling during the early design phase. It can also be efficiently used for creating variety of shell structures for architectural design.

Rind modeling consists of two steps. In the first automatic step, for any given 2-manifold mesh surface an offset surface is created based on the user defined thickness parameter. This gives us a crust or a shell, which has a manipulative structure. The second interactive step is punching or peeling the whole structure. For the same solid shell users can define a variety of face structures. As a result, different forms can be obtained from the same starting solid. Users can modify the raw product with different subdivision or other transformation algorithms in any time of the modeling phase. This remeshing or subdividing phase creates smooth and continuous solids from primary objects. We often use remeshing to enhance the form of the designed objects.

The main usage of this new method is to allow architects and students to manipulate the digital shell construction with punching, peeling or other transformers. The new method has many advantages over standard Boolean techniques to form shells. Unlike the nature of Boolean operations it is computationally simple and robust. It allows creating consistent structures with ease of processing. The rind modeling system is compatible with external (i.e. commercial) modeling systems. Users can import and export any polygonal models to process in our system with rind modeling tool.

The rind modeling method is implemented in C++ and FLTK. The system has Unix, Linux and Windows versions. For data exchange between modeling platforms, we use OBJ file structures. The application is capable of importing and exporting OBJ data for further processing and rendering.

The new method and tool can help professionals, educators and students to create unusual and non-platonic geometries to be implemented in fields of architecture and design. The method is also fertile to create different forms for interior architecture. The output interface and technique can be used in design studio courses for experimental projects or in professional practice. The paper includes products from design workshops and a graduate level shape-modeling course.

Motivation for Rind Modeling

The inspiration for the rind modeling came from Escher‘s drawings of rind shapes [Escher 94], and the intricate nested carved sculptures of the Far East. Figure 1A is an example of a nested elephant sculpture from India. A second elephant can be seen inside the first through the holes on outer surface. We have also seen nested balls from China that consist of up to 16 rotate-able balls carved inside of each other.

Although our original inspiration came from traditional art, such rind shapes are extremely useful in architectural and industrial applications. Many architectural and man-made objects are rind shaped. Examples are endless and include shell structures, buildings, industrial designs etc.

We have developed a user-friendly manifold modeling method that we call rind modeling. It allows us to construct easily very high genus rind shaped manifold surfaces. For example, the outer shape in Figure 1.B is a rind model created using our method and rendered with bump mapped textures. Figure 2 shows examples of spherical rind shapes. As seen in the figure, shapes similar to nested Chinese ball sculptures can be obtained by scaling and rotating the spherical rind shapes. Rind modeling consists of two steps: in the first (automatic) step, for any given 2-manifold mesh surface an offset surface is created based on a user defined thickness parameter. As a result of this step, from one surface two similar surfaces, a shell or a crust is created. The second (interactive) step consists of two modes, hole punching and peeling, similar to punching holes in a coconut husk or peeling an orange rind. Holes are punched by single mouse clicks.

The rind modeling method can also be used to create shapes that do not necessarily look like rind shapes. An example of such uses is shown in Figure 3. The surface in this figure looks more like an extruded surface than a rind surface, but it cannot be created as a simple extrusion because of its branching structure.

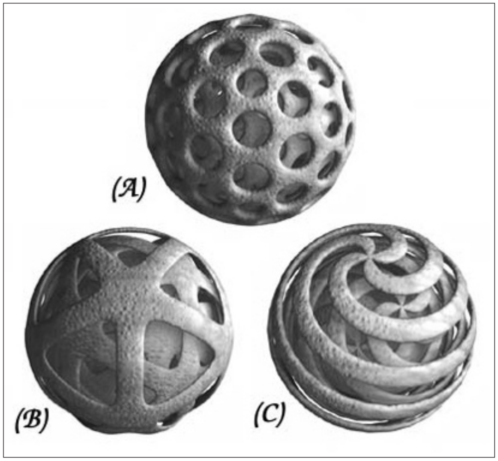


Figure 2
Two examples of spherical rind shapes. The nested structures are obtained by scaling and rotating the outer rind shapes.

Previous Work

Creation of very high genus manifold surfaces (surfaces with lots of the holes, handles and columns) has always been a research interest in computer graphics and shape modeling. Ferguson, Rockwood and Cox used Bezier patches to create high genus 2-manifold surfaces (Ferguson et al. 1992). Welch and Witkins used handles to design triangulated free-form surfaces (Welch and Witkins 1994). Using Morse operators and Reeb graphs, Takahashi, Shinagawa and Kunii developed a feature-based approach to create smooth 2-manifold surfaces with high genus (Takahashi et al. 97).

We have recently introduced Doubly Linked face List (DLFL) data structure and a topologically robust mesh modeling approach (Akleman and Chen 1999). We have also developed a minimal set of (four) operators (Akleman et al. 2003) that can effectively change the topology of a manifold mesh by inserting and deleting handles, opening and closing

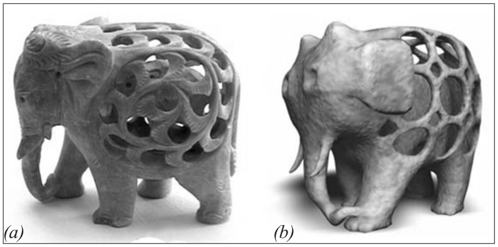


Figure 1
An example of nested sculptures from India. (A) shows a real nested elephant sculpture. (B) is a rind model created using our system and rendered with bump mapped textures.

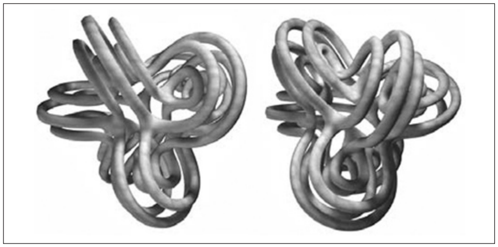


Figure 3
Two views of a shape that can be created by our method, but does not look like a rind shape. Smooth curves created by polygonal modeling+ subdivision remeshing.

holes, creating and deleting columns. These four operators can be efficiently implemented on almost every mesh data structure including winged-edge, (Baumgart, 1972), half-edge (Mantyla 1988) and quad-edge (Guibas and Stolfi, 1985). These operators can also be used to effectively implement subdivision schemes and allow topology change during subdivision modeling (AKleman et al. 2000, 2001a).

These results suggest that software development for mesh modeling with a topologically guaranteed orientable manifold property can be greatly simplified. We have recently developed a topological mesh modeling system (Akleman et al. 2001, Akleman et al. 2002). New high level and intuitive topology change operators can be constructed and added using only these four operators. A recently introduced high-level operator called CreatePipe (Akleman et al. 2002) is an example of such intuitive topology change operators. The CreatePipe operator connects two faces by automatically creating a pipe made up of only one segment whose ends are defined by the original faces. This automatic process helps the users to intuitively understand the topology change as creating a pipe between two faces. If this pipe goes through the inside of the surface (as happens in our application in this paper), it automatically punches a hole.

The CreatePipe operator is extremely useful for developing mesh design methods to create very high genus manifold surfaces.

Methodology

It is straightforward to develop a naive algorithm for the construction of high-genus rind surfaces based on the CreatePipe operator. This algorithm would proceed in two stages.

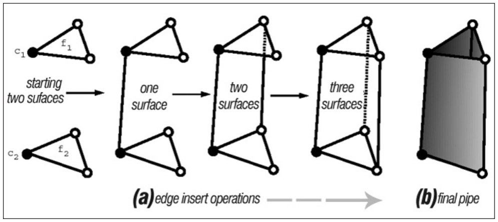


Figure 4
CreatePipe Operator.

Stage 1: Offset surface creation

1. Duplicate the initial mesh and move the vertices of the new mesh so that they will lie completely inside the first mesh (if the object is not convex or star-like, it may be necessary to further move some vertices). This operation creates two nested surfaces, which consist of the initial mesh and the newly created offset mesh.
2. Reverse the normals of the faces of the offset mesh. This operation changes the inside and outside of a 2-manifold mesh by changing the rotation orders of faces.

The second stage of the naive algorithm is needed to create such high genus shapes. In this stage, the users can choose to either simulate punching holes or peeling away parts of the rind.

Stage 2A: Hole punching

This stage consists of two topologically different steps. However, users perceive both steps as being same, namely, punching holes.

1. Connect two corresponding faces using the CreatePipe operation. This operation connects initial and offset surfaces and makes them a single surface. Formally, this first CreatePipe operation connects the two surfaces (i.e. changes the topology) but does not increase the genus (Akleman et al. 2002).
2. Using the CreatePipe operation, create additional holes. The CreatePipe operation after the first one both changes the topology and increases the genus by one (Akleman et al. 2002).

Stage 2B: Peeling

Punching holes does not automatically create a peeled effect. Punching holes in two neighboring faces leaves an infinitely thin wall or slab (like a thin membrane) between two neighboring holes. Users have to delete such infinitely thin walls to create a peeled look.

It can be assumed as a skilled user can create almost any very high-genus manifold rind shape with this naive algorithm. This observation is theoretically correct, but, practically, because of several „severe“ usability problems it is not easy to create complicated rind surfaces even by skilled users. The usability problems we have identified can be summarized as follows.

Usability problem with offset surface creation

It is not easy to create an offset surface by hand for complicated initial meshes. It is also very difficult to form offset surfaces from high-genus initial meshes.

Usability problem with hole punching

It is not easy to select two corners of two related faces in both the initial and offset surfaces for opening holes with the CreatePipe operator. It is especially difficult to select a correct corner in the offset surface since this surface is inside and partially visible only through holes. This difficulty is even more pronounced in the application of the first CreatePipe operation that connects two surfaces since initially the offset surface is completely invisible.

Usability problem with hole punching

The peeling stage of the naive algorithm requires users eliminates the walls. Each of these walls consists of two quadrilaterals like a folded paper. Since all edges are straight, this wall looks like a two sided quadrilateral but it is not. There are additional edges needs to be deleted. Therefore, this deletion process is very hard for the users. They may forget to delete some edges and these edges may create problems later stages of the design. As a result, it is better to delete walls automatically, preferably with a very simple and fast operation.

Semi-Automatic Approach

We solve the usability problems with a semi-automatic approach. When the user selects a manifold surface and then chooses rind modeling mode, the system automatically creates an offset surface based on the value of a user set thickness parameter. Then users either punch holes or peel by simply selecting faces. While peeling, the infinitely thin pipes between neighboring holes are automatically eliminated. The following is our semi-automatic method:

Automatic step: Offset surface creation

This is the first operation after the user selects rind modeling mode.

1. Duplicate the initial mesh to create an offset mesh, reverse the normals and compute average unit normals for each vertex.
2. Create a correspondence table that records the corresponding faces of the initial and offset meshes. The correspondence table also includes one corresponding corner for each face.
3. Move each vertex of the offset mesh in the direction of its average normal vector a distance equal to the thickness value.

This procedure may result in self-intersection for high values of the thickness parameter. We avoid self-intersections by simply using smaller thickness values.

After the offset surface has been (automatically) created, the interactive step is initiated. During the interactive step, the system can be in two modes: hole punching and peeling. The user can change the mode during the interactive process. As soon as the offset surface is created users see a message that says ``select a face to punch holes“ or ``select a face to peel“ depending on the chosen mode. Then they can either punch holes (or peel depending on mode) by simply selecting faces of either the initial or offset surfaces.

Interactive step: Hole Punching Mode

The algorithm for punching one hole is extremely simple.

1. Find the selected face in the correspondence table.
2. Using the two faces and two corners obtained from the table, apply CreatePipe.

If the users select a face that is not in the correspondence table, the procedure ignores the selection.

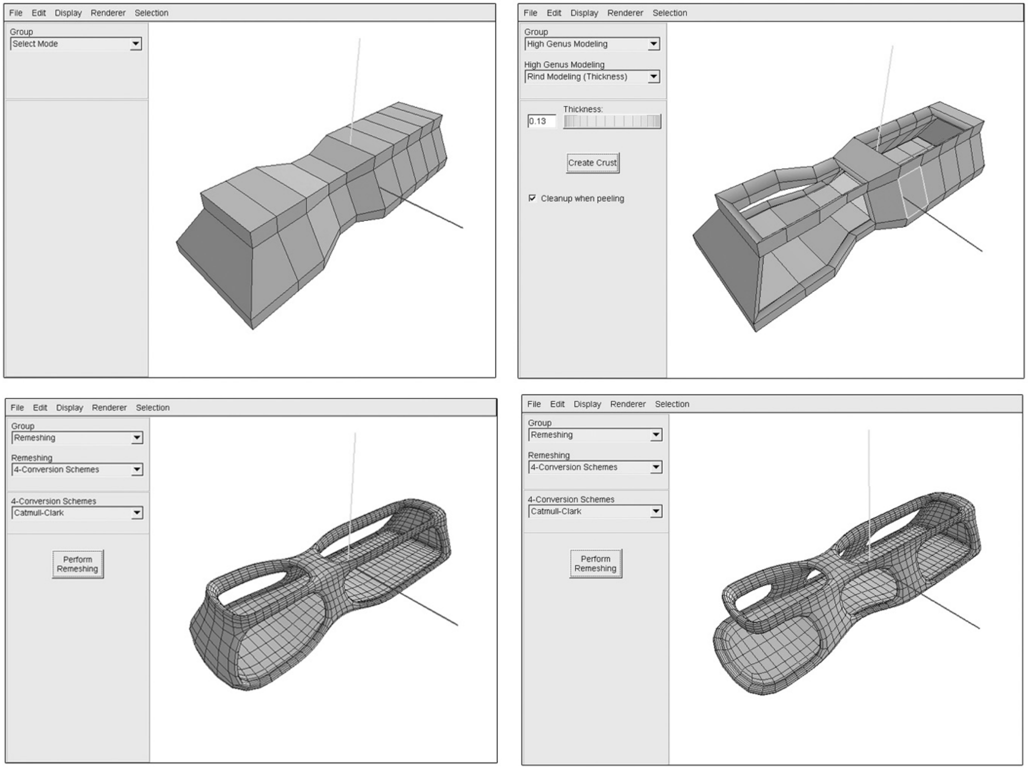
Interactive step: Peeling Mode

In peeling mode, every infinitely thin pipe created as a result of punching holes is deleted. The procedure for cleaning such unwanted walls also turned out to be extremely simple.

1. Find the selected face in the correspondence table.
2. Using the two faces and two corners obtained from the table, apply CreatePipe.
3. For every corresponding two edges of the old (recently deleted) faces of the initial and offset surfaces, check adjacent polygons. If the adjacent polygons are the same, delete all the edges of the quadrilateral face that includes the two corresponding edges.

Interface, Implementation and Results

The procedure above is included in our existing 2-manifold mesh modeling system Akleman et al.



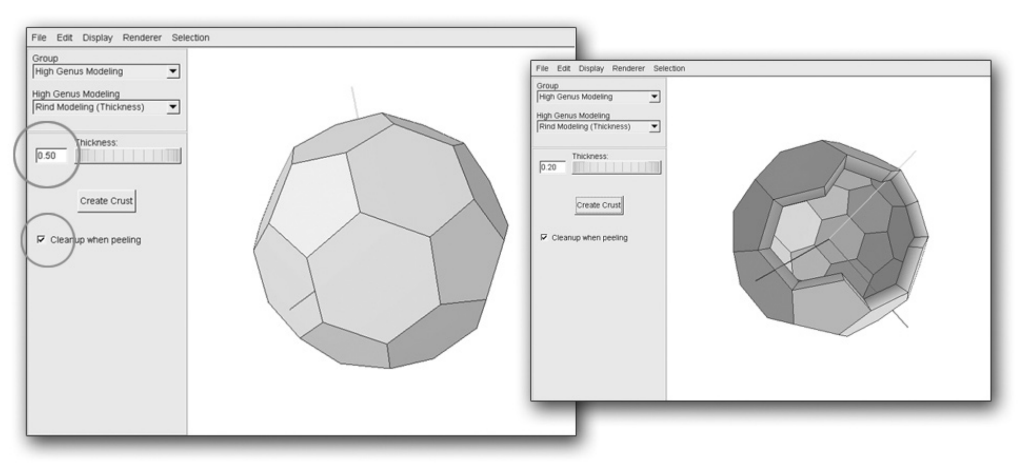
Group: Select Mode

Group: High Genus Modeling
High Genus Modeling: Rind Modeling (Thickness)
Thickness: 0.13
☑ Cleanup when peeling

Group: Remeshing
Remeshing: 4-Conversion Schemes
4-Conversion Schemes: Catmull-Clark

Group: Remeshing
Remeshing: 4-Conversion Schemes
4-Conversion Schemes: Catmull-Clark

Figure 5
An example for conceptual model development. Smooth surfaces made with subdivision remeshing schemes.



Group: High Genus Modeling

High Genus Modeling: Rind Modeling (Thickness)

Thickness: 0.50

☑ Cleanup when peeling

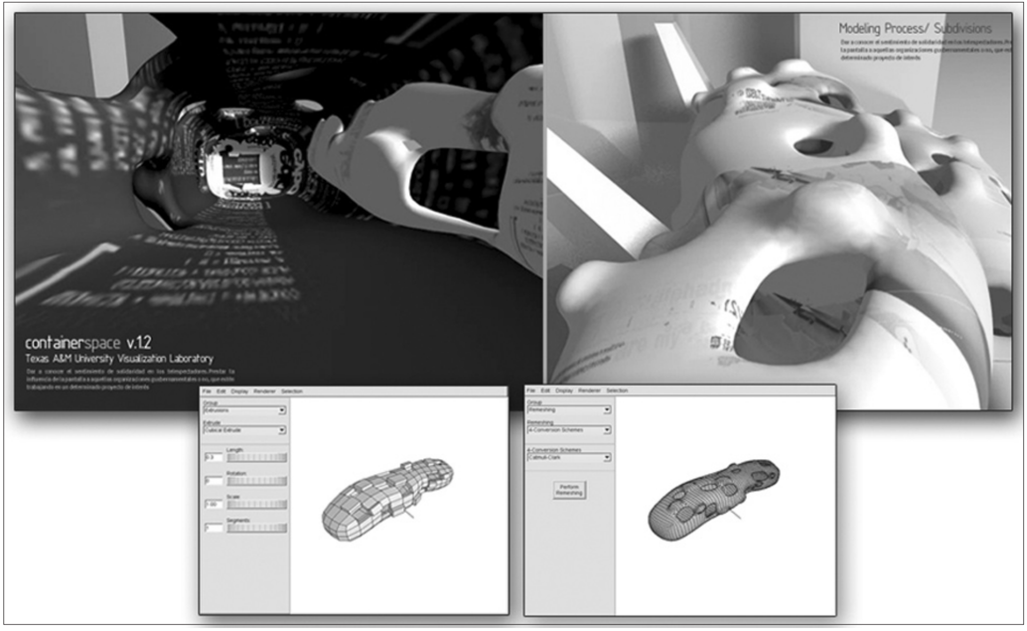
Group: High Genus Modeling

High Genus Modeling: Rind Modeling (Thickness)

Thickness: 0.20

☑ Cleanup when peeling

Figure 6
Screenshots from the Interface.


containerspace v.1.2
Texas A&M University Visualization Laboratory
Dar a conocer el sentimiento de solidaridad en los teleespectadores. Prestar la influencia de la pantalla a aquellas organizaciones gubernamentales o no, que estén trabajando en un determinado proyecto de interés
Modeling Process/ Subdivisions
File
Edit
Display
Renderer
Selection
Perform Remeshing

Group: Extrusions

Extrude: Cubical Extrude

Length: 0.3

Rotation: 0

Scale: 1.00

Segments: 1

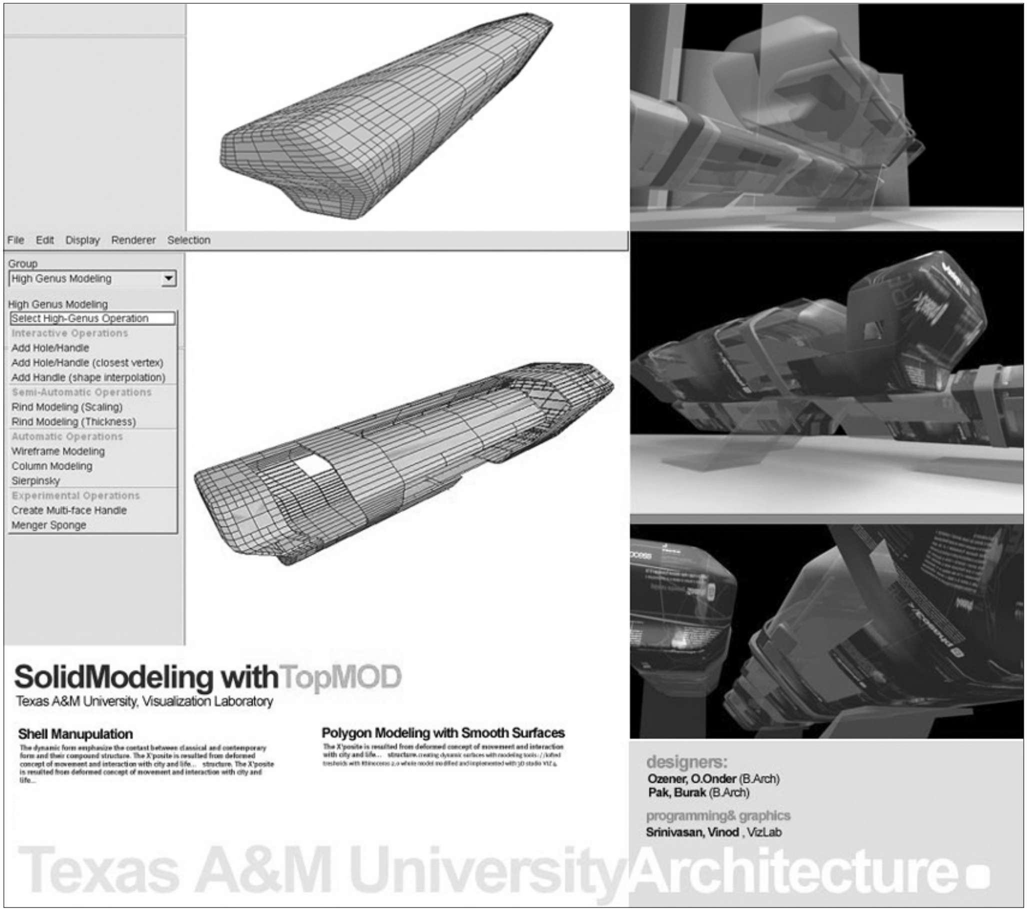
Group: Remeshing

Remeshing: 4-Conversion Schemes

4-Conversion Schemes: Catmull-Clark

Figure 7
A conceptual design work with our system.

2002 as an option. Our system is implemented in C++ and FLTK. The system can run on Unix, Linux and Windows platforms. The User Interfaceface consists of parameters for crust generation and subdivision remeshing schemes. User can easily define the crust thickness to form the shell. After the explained operations, remeshing modifiers can be applied for smooth shaped shell structures. The prototype software is capable to generate Alias OBJ file to establish a connection between popular 3D software like MAYA and 3D Studio MAX/VIZ. All the examples in this paper were created interactively using this prototype system. The usability of the system was tested in a graduate level shape-modeling course in which a majority of the students had an architecture undergraduate background and several workshops. Some examples of these students work are shown in Figures 7, 8 and 9. Although none of the students had any previous idea about topology, they easily learned to use the software and created a wide variety of high genus manifold meshes and shell structures as one of their



SolidModeling withTopMOD

Texas A&M University, Visualization Laboratory

Shell Manupulation

The dynamic form emphasize the contast between classical and contemporary form and their compound structure. The X'posite is resulted from deformed concept of movement and interaction with city and life... structure. The X'posite is resulted from deformed concept of movement and interaction with city and life...

Polygon Modeling with Smooth Surfaces

The X'posite is resulted from deformed concept of movement and interaction with city and life... structure.creating dynamic surfaces with modeling tools: / lofted tresholds with Rhinoceros 2.0 whole model modified and implemented with 3D studio VIZ 4.

designers:
Ozener, O.Onder (B.Arch)
Pak, Burak (B.Arch)
programming& graphics
Srinivasan, Vinod , VizLab

Texas A&M UniversityArchitecture

Figure 8
An example of using rind modeling to modify a shell model for conceptual design.

weekly class projects.

Conclusions

In this paper, we presented a user-friendly modeling method to easily construct very high genus rind shapes. We also successfully implemented the concept to a mesh modeling interface. Our semi-automatic method is simple and easy to implement. Our semi-automatic method simplifies the modeling process, but there are many applications that can be done with complete user control but not with our approach. For instance, users can easily modify using offset surfaces that do not have the same mesh structure as the initial surfaces. The creation of offset surfaces that do not have the same mesh structure as the initial surfaces is just one part of the problem. More interesting points can also be a direction for fertile algorithms. Further studies on modifying algorithms for different cases in rind modeling concept will be interesting designers to model unusual forms.

Consequently usage of rind modeling concept may allow designers to create non-platonic shapes and shell structures for architectural design. The modeling approach of the system gives designer an option to rethink the solid model as a boundary between inner and outer space and redesigning this boundary with given modifiers. Being a very flexible system, our software is open to incorporate different rind modeling ideas and feedbacks from designers.

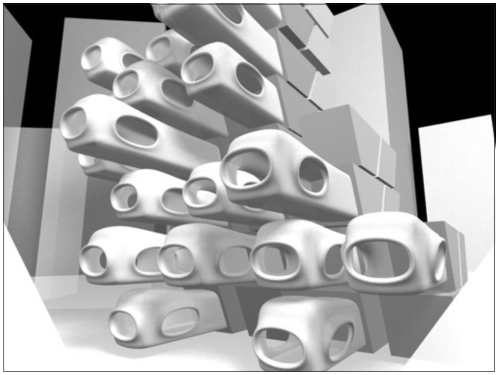


Figure 9
A conceptual design work with our system.

References

Akleman E. and Chen J., 1999, Guaranteeing the 2-manifold property for meshes with doubly linked face list, selected for special issue of International Journal of Shape Modeling, Volume 5, No. 2 pp. 149-177,.

Akleman E. and Chen J., and Srinivasan V.,2000, A new paradigm for changing topology during subdivision modeling, Proceedings 8th Pacific Conference on Computer Graphics and Applications, (PG'2000), (2000), pp. 192-201, Hong Kong, China. Oct. 2000.

Akleman E. and Chen J., Srinivasan V. and Eryoldas F.,2001, „A New Corner Cutting Scheme with Tension and Handle-Face Reconstruction", Selected for special issue of International Journal of Shape Modeling, Volume 7, No. 2, pp. 111-121, 2001.

Akleman E. and Chen J., and Srinivasan V, „An Interactive System for Robust Topological Modeling of Meshes", Visual Proceedings of ACM SIGGRAPH'2001, Los Angeles, California, August 2001.

Akleman E. and Chen J., and Srinivasan V,2001, „An Interactive Shape Modeling System for Robust Design of Functional 3D Shapes", pp. 248-257 Proceedings of ACADIA 2001, Buffalo, NW. October 2001.

Akleman E. and Chen J., and Srinivasan V, 2003, „A minimal and complete set of operators for the development of robust manifold mesh modelers", Graphical Models Journal, Volume 65, Issue 5, pp. 286-304, September 2003.

Baumgart, B. J. ``Winged-edge polyhedron representation", Technical Report CS-320, Stanford University, 1972.

Catmull E. and Clark J., ``Recursively Generated B-spline Surfaces on Arbitrary Topological Meshes", Computer Aided Design, 10 (September 1978) 350-355.

Escher M. C., The graphic works: introduced and explained by the artist, image plate 41 and 43, Barnes and Nobles Books, New York, 1994.

Ferguson H., Rockwood A. and Cox J., ``Topological Design of Sculptured Surfaces“, Computer Graphics, 26 (August 1992) 149-156.

The Fast Light Toolkit Home Page: http://www.fltk.org/

Fomenko A. T. and Kunii T. L., Topological Modeling for Visualization, (Springer-Verlag, New York, 1997).

Guibas L., Stolfi J., 1985, ``Primitives for the manipulation of general subdivisions and computation of Voronoi diagrams“, ACM Transaction on Graphics, 4 (1985) 74-123.

Mantyla M. 1988, An Introduction to Solid Modeling, Computer Science Press, Rockville, MA, 1988.

Senagala, M. 2001 Production pf Digital Space: On the Nature of Digital Materiality, Architectural Information Management [19th eCAADe Conference Proceedings / ISBN 0-9523687-8-1] Helsinki (Finland) 29-31 August 2001, pp. 348-351

Takahashi S., Shinagawa Y. and Kunii T. L., ``A Feature-Based Approach for Smooth Surfaces“, in Proceedings of Fourth Symposium on Solid Modeling, (1997) pp. 97-110.

Welch W. and Witkin A., 1994 ``Free-Form Shape Design Using Triangulated Surfaces“, Computer Graphics, 28 (August 1994) 247-256.

Zorin D. and Schroder P., 2000, co-editors, Subdivision for Modeling and Animation, ACM SIGGRAPH‘2000 Course Notes no. 23, July, 2000.