**Component-Based Adaptive Shell Structure**

Haruna Okawa, Keio University

http://harunakawa.com/

1. Introduction-The Scaffold Problem and Non-Linear Assembly

Shell-structured buildings have been explored by many architects and structural engineers, of them constructed in a different way. For example, L’Oceanogràfic (2003), designed by Félix Candela used a wooden mould to cast its concrete shell. Although this method is popular for concrete shell construction it leaves a lot of waste once the concrete is cured and the formwork is removed. Another example, Mannheim Multihalle (1974) by Frei Otto is more efficient because it does not require a formwork. Instead a wooden lattice was built on the ground and the application of specific pressure to the total form created a complex three-dimensional curve. However, its formal transformation depended on the application of stress on the structure, making the shell material weaker. These works are traditional examples of static shell structures. By looking at the relationship between the shell design and its construction method, a critical point is noticed in the transformation strategy that turns the structure into a self-optimized shell structure. The significance of this outcome is the non-linear shell-forming process that takes place in the final stage. Components can go through three different structural modes: flat, tensioned, and pressured. The method is non-linear in that the shape does not form slowly as forces are applied, but rather takes place suddenly after a threshold is reached. When combined together, it behaves like a cloth. Yet, thanks to the component system, the number of components can be incremental and literally infinite variations in shape is available.

2. Concept-A Pop-up Shell, Self-Optimized Shape

The idea is to create a Pop-up Shell that can appear and disappear in a relatively short time. The pop-up process consists of three steps: (1) Transport, (2) Placement, and (3) Stressing. Firstly, the units are placed on a flat surface. Then, they are placed to form a hexagonal grid. By adding pressure, it will eventually pop-up and form a self-optimized shell structure. The significance of this outcome is the non-linear shell-forming process that takes place in the final stage. Components can go through three different structural modes: flat, tensioned, and pressured. The method is non-linear in that the shape does not form slowly as forces are applied, but rather takes place suddenly after a threshold is reached. When combined together, it behaves like a cloth. Yet, thanks to the component system, the number of components can be incremental and literally infinite variations in shape is available.

3. Component Design and Simulation

-Surface Morphology, Hex Block with Three Legs

The component is a hexagon with three legs attached. Each component can be connected to six adjacent parts with ribs that prevent them from separating. As an aggregate it can move as a cloth, and under the right conditions it becomes a shell structure. In the pseudo-simulation, the aggregate of hexagonal units is replaced by a single surface (and in this way is not a full simulation). The surface is transformed to simulate the physical form-making process. Its four corners are set as anchor points which give the surface a three dimensional form when moved. The centroids of each unit are located on this surface and move as the surface is transformed. The height and overall shape correspond with the distance the anchor points have moved. Finally, the surface is evaluated at each point and normal vectors are acquired. Following the position of the points and direction of the vectors, the components are placed, creating a shell shape based on the simulation. Depending on the length of the legs, the stretch of the surface is determined.

4. Materialization-CNC-milling, Folded Urethane Sheet

Several scale models were made before the full-scale shell was built in order to test fabrication methods and to explore the effect of changed parameters of the individual components, including materiality and connecting details. The final material used to build the 1:1 scale model is a hard urethane sheet (Adhesive Board A/L/PE Non-CFC), with an aluminum sheet bonded to its top surface and waterproof paper on its bottom. A sheet is 900mm by 1620 mm and 10mm thick. In this case 12 sheets were used to make the model. In terms of fabrication, the shapes were cut with Shopbot and each piece then folded manually. Usually, hard urethane cannot be folded because it will easily crack, however the addition of aluminum to the front face resolves this issue, so that a folded structure could be produced.

5. Results and Feedbacks-Lightness vs Hardness

The self-supported shell is composed of 34 individual pieces. The simulation was useful as a tool during the design process, giving an indication of the final shape of the shell structure. As a responsive system, changes made to the surface and the components revealed different shapes. Criteria that had significant impact included the placement of the components, changes in the shape of the initial surface, as well as the direction and amount of anchor points. By scaling up the shape, the lightness and hardness of the material were crucial elements and the urethane sheet was found to perform best in terms of rigidity and strength. The precision of fabrication and gap between the individual components were key factors to take note of in the built model as they defined how smoothly the components moved and how strongly the friction connection worked to maintain the final shape under real-world conditions.


The simulation process be improved in the next stage of this research. Instead of regarding the body as a single surface, collisions between multiple three dimensional objects will be detected as force is applied. In this way the structural transition process and stress lines can be simulated more precisely. This will also enable structural optimization of the component. Also, better fabrication methodology should be explored as there is inevitable inefficiencies of nesting irregular shapes on flat sheets for CNC cutting. Possible solutions include but not limited to create frames, inflatable balloons, and so on by hand, 3d printer, moulding, et cetera.

7. Conclusion-Adaptive Shell

The chained block structural system enabled the creation of an adaptive shell that moves between different structural states. The range of each component’s movement is controlled as they defined how smoothly the components moved and how strongly the friction connection worked to maintain the final shape under real-world conditions.

References


Princeton, N.J. :