

# Design and Fabrication

## CAD/CAM for the Installation of a Staircase

by **Chen-Cheng Chen, Hung-Ming Chen, and Chen-Chia Li**  
Tamkang University  
Tansui, Taiwan

The Tamkang University College of Engineering is in an eight-story building. Sunlight hits the building from the southeast and the huge curtain walls running from the fifth to eighth floor stairwells provide a good place for the students to enjoy the sun in nice weather. Therefore, the College of Engineering offered funds to students in the Department of Architecture to create an even more convenient rest area in the stairwell. We thought this was a great opportunity and we accepted it, pleased with the commission to both design and construct. There are about eight familiar landings from the fifth to the eighth floors of both sides of the building, each one 6 meters long, 5 meters wide and 3.5 meters tall. We started with the one nearest to the main entrance on the sixth floor as our design area (Figure 1). Teachers in the College of Engineering had seen some smaller projects our students created with CAD/CAM technology, so they more than welcomed us to continue using CAD/CAM in a similar way for this small-scale design.

### Design description

After acceptance of the proposal and after a month of discussion, we concluded that the main function of the resting area should focus on an attractive installation and seat, where students and teachers could rest or exchange ideas during break time (Figure 2 and 3). The College of Engineering committed to support us with about 3,500 USD to cover the cost of materials. After consideration of the budget, we decided that the materials would mostly be 1.8 cm thick plywood boards. After that, we spent a little more than three months (from August to November 2008) modeling in form•Z, rapid prototyping, converting and treating the surfaces, employing computer-aided manufacturing and processing methods, and finally assembling our creation (Figure 4).



Figure 1: The original stairway landing pre-construction.



Figure 2: A computer simulation of the view of the project from outside the staircase.

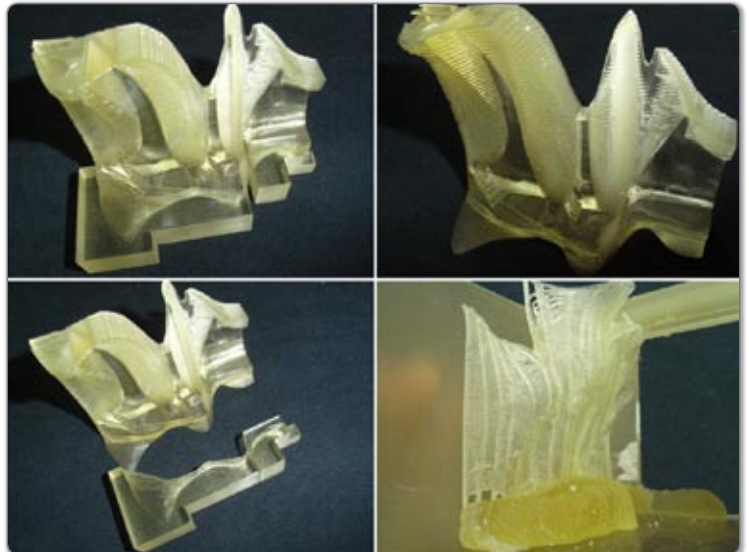


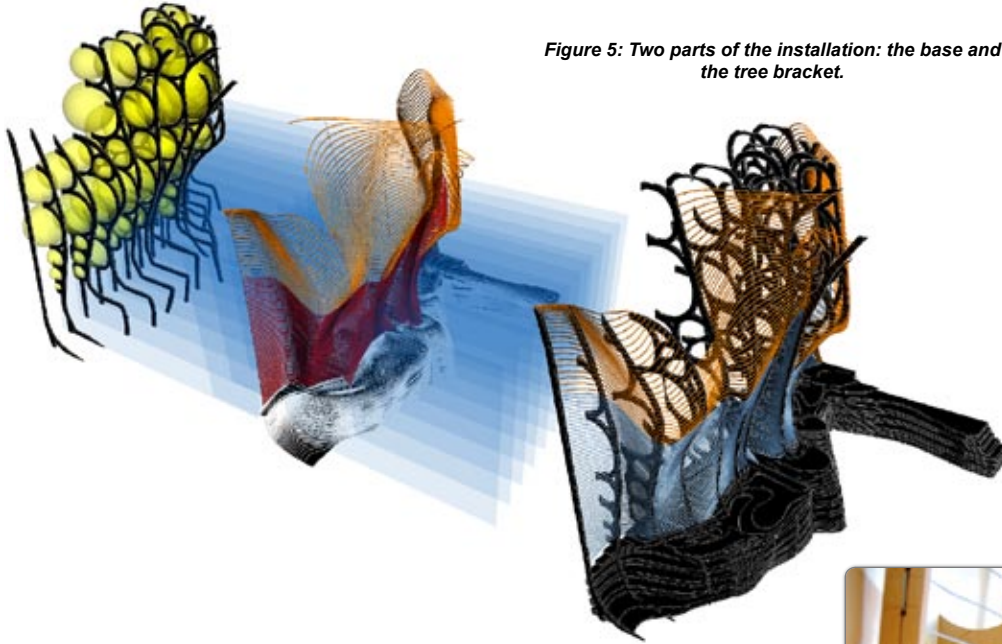
Figure 3: The rapid prototype model.

The approximate size of the design was derived from extending the scope of the possible seating area all the way to the ceiling. It consists of 15 profiles that were produced by a continuous section. Initially we constructed the shape of the installation with NURBS and then we processed the design to add more details. The whole installation includes two parts: the base and the tree stand. The base is the seat for the students. The upper part is the tree stand, which is intended to give the impression of a plant (Figure 5).



*Figure 4: Assembly process.*

*Figure 5: Two parts of the installation: the base and the tree bracket.*



Sitting between the base at the bottom and the stand at the top, one feels like he is sitting in the shade under a tree on the hill. The base is interlaced from the bottom to the top, combined to form a continuous base (Figure 6) and there is fixed spacing with the upper part of the tree stand at the same time (Figure 7).



*Figure 6: The continuous base stacked up with staggered boards.*



*Figure 7: Connecting of junction of the tree bracket and the base.*

The top of the tree stand consists of two main parts:

a. Tree columns: There are thirteen uniquely spaced tree columns. The empty space in the middle of the tree columns lightens the static load of the structure itself and 1.8 cm homogeneously thick pieces of plywood extend to a height of 3.5 meters (Figure 8).

b. Cable network: The mesh is woven with stainless steel cables. According to the NURBS surface curvature, there are 38 round holes in the outer structure of each column. The woven wall surface generates lateral forces to ensure that a structure that extends to the ceiling will not have any lateral displacement (Figure 9).

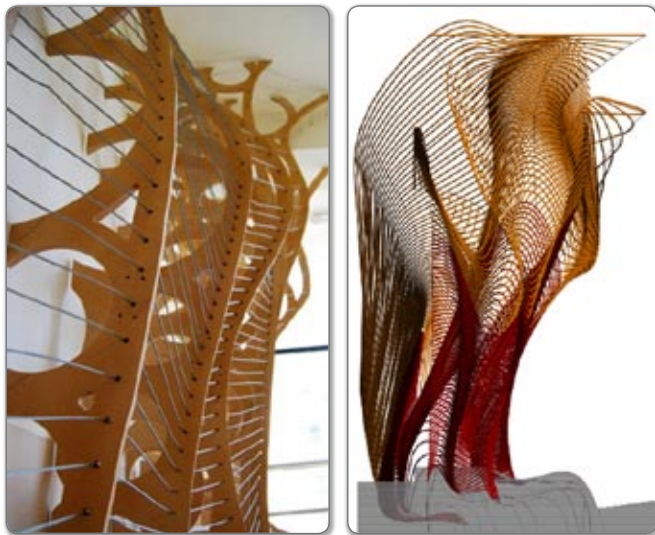


Figure 8: Detail of horizontal network cable and the diagram.



Figure 9: Upper tree bracket.

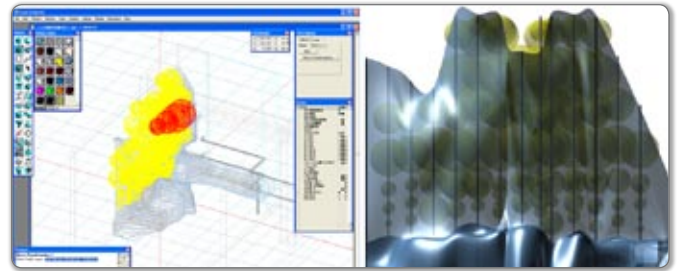


Figure 10: The replication and sphere gradient structure operated by the commands of Marco in FormZ.

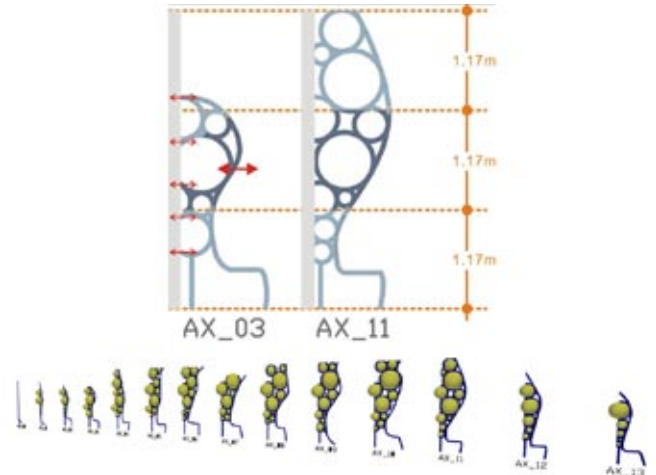


Figure 11: Diagrams of the tree bracket being made from the big and small spheres and the continuous sphere relation.

### Computer model and simulation

The tree columns were initially derived and generated by continuous arrays of spheres, using the Macro Transformation tool, which allowed us to integrate movement. Beginning at the top of the sphere, we successively selected each sphere and used the Line of Intersection tool to derive curves on both the horizontal and the vertical axes of the spheres, which gave us both the original spheres and the newly derived curves. After this step, we applied Boolean operations and removed the sphere, which left us with the tree columns (Figure 10 and 11). In addition, we used Animation tools to combine rules and paths, and we easily simulated the possible distributions of the real object. The surface structure was constructed with NURBS and, as the curve density came close to the stress requirements of the real object, we ended up with a relatively stable structure. The surface was further adjusted using the Reconstruct NURBS tool. The minimum distance between the levels of curves was just above 6 cm, and we used the Extract Curve tool to get the UV curves, which were then used to generate each structural element and the net of the surface area (Figure 12). The array of lines in the NURBS curvature was intensive and, at the same time, the horizontal cables crossed over this intensive section, and vice versa.

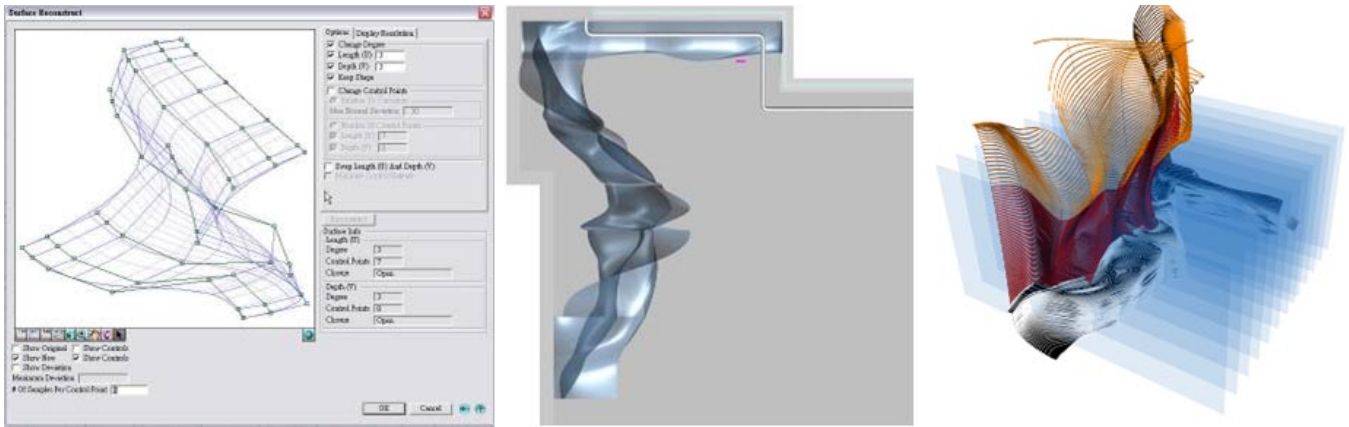


Figure 12: The structural process of adjusting the UV surface structure to a network in NURBS.

### Construction process

Construction of the Base: The base is stacked up from the bottom to the top with different partitions of odd and even layers, with two-thirds of each layer overlapping in two ways. Within the same layer, there were different subdivision methods, and each division was manufactured separately. The segmentation system is shown in Figure 13. The blue lines are the odd layers and the orange lines are the even layers. After segmentation, we removed the plate distribution in the middle and arranged a continuous base with the fewest number of horizontal plates. Based on three rules of arrangement, we inserted tenon joints with three different height ratios (1:3:5) into horizontal gaps of different sizes (Figure 14). We inserted the tenon joints into the pre-drilled well of the horizontal boards and the holes were distributed in a matrix, which not only saved us a lot of time, but also lightened the materials and the loads. Boards were stacked in three arrangements with five modular components. The modular units not only increased the freedom of assembly, but also, through manual assembly, maintained the precision of digital manufacturing (Figure 15). The small to big, bottom to top constructional relationships produced a rhythm visually.

Construction of the upper tree bracket: The digital lathes we use are smaller, so we had a length and width restriction of 1.20 meters. We had to process the 3.5 meter slab-columns separately and then joined them to extend the structure. We didn't use any industrial joints in this design. Instead, we used joints made from the same materials. Considering the texture of the materials, we arranged the biggest cross section of columns to fit within a 60 mm framework. To keep the thickness of the board (1.80 cm) and to have enough structural strength, we combined "scarf joints" and "friction joints" into compound joints. Subject to the limitations of distance and thickness and using CNC precise geometric cutting, we were able to process the

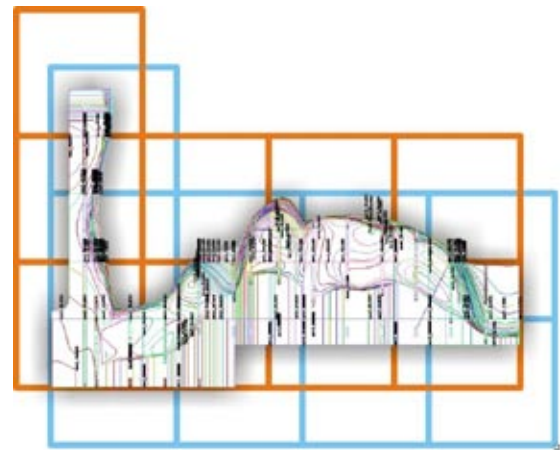


Figure 13: Schematic diagram of the base board segmentation (Blue lines: odd layers. Orange lines: even layers).



Figure 14: Diagram of variously proportioned base joints.



Figure 15: Base joint components and the process of assembly.

compound structure with all its size changes. Going from numerical terms to physical structures to build and develop this detailed unit, the rules of the processing, materials and size limitations and other conditions are as follows: multiple angles of the cutting tool (Figure 16 R values) must be greater than or equal to 0.3 cm when processing the joints, the vertical distance between a tenon going through a board (Figure 16A) and the laminated surface of the board (Figure 16B) must be even, and then we can calculate the largest section of the joints (Figure 16C's circumference).

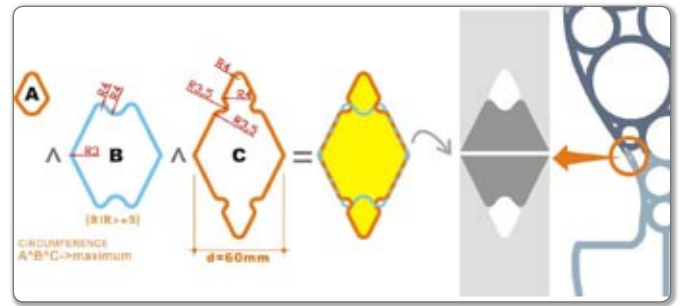


Figure 16: Tree column joints with different R values.

The larger the contact area of the joints attached to the pillar section, the better the resistance to lateral deformation. There are two kinds of joints that meet the same rules and after testing of the units, the closer the average R value is to 0.3 cm the better (Figure 17, Right). To process the tenons precisely, we used a tool to inlay them evenly into the notch of the pillar's joints, and then we were able to assemble upward (Figure 17, Left).

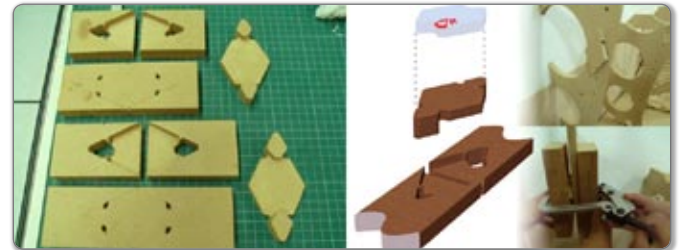


Figure 17: Left: joints of the tree column pillars. Right: the assembly of these joints.



Figure 18: Photo after completion.

## Afterthoughts

Development of the actual object from the model of the computer graphics: We can use form•Z commands that apply to the digital manufacturing process and produce a corresponding relationship between the virtual and actual environment. For example, Sweep is similar to “extrusion forming”, Loft is similar to “vacuum forming” and 3D extrusion is similar to “milling.” Modeling commands are analogous to the actual developmental process of producing the real objects and can simulate their production.

From digital manufacturing to digital fabrication: It is not difficult to make complex surfaces through CNC component production. Parameters can be adjusted in the design and manufacturing, which reduces the difficulty of processing before setting out. Throughout the entire process, we didn’t output any plane, façade or section drawings. Instead we had the component numbers and the 3D transparent rendering map from the simulation of the group structure. In total, there were 335 pieces of plywood (1.2 meters long and wide).

From virtual simulation to actual model: Unlike the past, when part of the construction or manufacturing process had always been outsourced to others, in this experiment, the designers not only had to consider the integration of materials and production and construction technology but also had to integrate digital tool

software, manufacturing software and the machinery. The process of applying graphics software and thinking about data structures, from the physical simulation to the structural materials and even to the integration of processing and assembly, made this a unique process unlike traditional design and manufacturing processes.

## Conclusions

The project was to make a computer model of a 3D virtual space, to transform it into a 2D drawing, and to implement it into an actual area. The designers were very fortunate to have at their disposal such an accurate process that took them from CAD to CAM. Upon completion of this installation, many students have been attracted to linger in this area after class. Putting this interesting installation into an originally monotonous space has caused many discussions among the teachers and the students of the College of Engineering. Had we not been able to use CAD/CAM technology, this complicated design would have been very difficult to complete by hand (Figure 18).

## Acknowledgements

We wish to express our gratitude for the support of this design to the College of Engineering and especially the great support by Dean Gwo-Hsing Yu, without whom this project would not have been possible. We also want to thank the Jury of the form•Z Joint Study 2008-2009 Awards, for selecting this project for an Award of Distinction in Digital Fabrication, which has given us much motivation for the future.

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**Chen-Cheng Chen:** For photo and bio please see page 53.



**Hung-Ming Chen** is a Ph.D student and instructor at the Department of Architecture, Tamkang University. His project, “Installation of a Staircase,” on which he worked with Chen-Chia Li, received an Award of Distinction in Fabrication from the form•Z 2008-2009 Joint Study Program. His current research interests are focused on computer-aided design and manufacturing. He received his B.A. and M. Arch. from Tamkang University. Email: point19800@yahoo.com.tw.



**Chen-Chia Li** was a graduate student at the Department of Architecture, Tamkang University, 2007-2009. His project, “Installation of a Staircase,” on which he worked with Hung-Ming Chen, received an Award of Distinction in Fabrication from the form•Z 2008-2009 Joint Study Program. Currently, he is working for Bio-Architecture Formosana. He received his B.A. and M. Arch. from Tamkang University. Email: ilovekaede0917@yahoo.com.tw.