B. Dave, A. I. Li, N. Gu, H.-J. Park (eds.), *New Frontiers: Proceedings of the 15th International Conference on Computer-Aided Architectural Design Research in Asia CAADRIA 2010,* 239–247. ©2010, Association for Research in Computer-Aided Architectural Research in Asia (CAADRIA), Hong Kong

FABRICATING TWISTED TOWERS

BECHIR KENZARI
UAE University, Al-Ain, U.A.E.
b.kenzari@uaeu.ac.ae

Abstract. The miniature replicas of multi-billion dollar property development projects provide every year a spectacle of the vast imagination of architects and master developers at Cityscape Dubai exhibition. The technical aspect of the model-making industry component is a complex one in that it often engages the modelling of very subtle structures such as twisted towers. One illustration of these is the Infinity Tower in Dubai Marina (designed by SOM). To be completed in 2011, this 330-metre high-rise is composed of 80 floors and is intended to be the world's tallest high-rise featuring a 90˚ twist. Each floor rotates by 1.2 degrees to attain the full 90˚ spiral, creating the shape of a helix. The paper discusses the physical modelling of this tower, with a description of both the digital and the constructive parts.

Keywords: Fabrication; models; Rhinoceros; twisted towers; Dubai.

1. Introduction

The Arabian Gulf's oil-fuelled property sector is promoting many businesses, including the model-making industry. The miniature replicas of multi-billion dollar property development projects provide every year a spectacle of the vast imagination of architects and master developers at Cityscape Dubai fair. The technical side of this model-making industry category is a complex one, though, as it involves the modelling of very subtle structures such as twisted towers. The fabrication of these miniatures implies new domains of expertise that do not fall within the bounds of traditional modelling-making techniques. Issues of flexibility, precise contouring and unrolling/smashing manipulations are at work to achieve the construction of the desired non-uniform polysurfaces. It also involves operations such as the folding of several webs, which implies the introduction of material processes that are as new as they are complex. We recall, for example, how the design and construction of the Yokohama Terminal required a basic development operation whereby the folds of the web were woven with each other every half fold, so that the curvature at a larger scale could be secured (Moussawi and Zeara Polo, 2002).

Beyond their attractive presentations at fairs, twisted structures imply meticulous and detailed planning and unquestionable degrees of sophistication. One specific example is the SOM-designed Infinity Tower in Dubai Marina (figure 1). To be completed in 2011, this 330-metre-high structure is composed of 80 floors and is supposed to be the world's tallest tower featuring a 90˚ twist. Each floor rotates by 1.2 degrees to achieve the full 90˚ spiral, creating the shape of a helix. The shape of the tower is a variation on HSB Turning Torso in Malmö, Sweden, designed by Spanish architect Santiago Calatrava, which also twists exactly 90 degrees.

Figure 1. Dubai Infinity Tower.

Dubai Infinity Tower is located in the Dubai Marina, a city-within-a city and possibly the world's most exclusive waterfront development, where a stylish, sophisticated lifestyle has been created to delight its residents. The building's unique spiral design means that every apartment will have a view of the sea and marina in a truly unique setting. The Marina is ideally located for easy access to the Jebel Ali Free Zone, Dubai International Airport, Dubai Internet City and Dubai Media City, and some of Dubai's finest five-star hotels.

To design the Infinity Tower, the architects have used open-space architectural concepts to ensure that there are no pillars anywhere in the building, thus creating a true sense of space and light. Pre-finished titanium metal panels on cast-in-place concrete perimeter columns along with repetitive staggered screen panels filter the direct sunlight to the units. The tower's slender elegance conceals great strength; secured by a reinforced concrete column superstructure that rotates with the twisting shape to create a helix. The shape and size of these columns has been determined by wind tunnel testing and innovative engineering using 3D computer modelling analysis. At all times, in creating such a unique and radical architectural project, safety and stability have been the architects' primary concern, both in design and in the quality of materials and construction. Every stage of the Infinity project has harnessed the skills and experience of world-class professionals in every field. The building itself is still under construction (figure 2).

Figure 2. Dubai Infinity Tower under construction (May 2009).

2. Modelling

Back in the days before computers, architects, engineers, and artists would draw their designs for buildings, roads, machine parts, and the like by using pencil, paper, and various drafting tools (Schneider, 1996). These tools included rulers and T-squares for drawing straight lines, compasses for drawing circles and circular arcs, and triangles and protractors for making precise angles. Of course, a lot of interestingly-shaped objects couldn't be drawn with just these simple tools, since they had curved parts that weren't just circles or ellipses, and which needed to run smoothly through a number of predetermined points. This problem was particularly acute in shipbuilding. Although a skilled artist or draftsman could reliably hand-draw such curves on a drafting table, shipbuilders often needed to make life-size (or nearly life-size) drawings, where the sheer size of the required curves made hand drawing impossible. Because of their great size, such drawings were often done in the loft area of a large building, by a specialist known as a loftsman. To aid in the task, the loftsman would employ long, thin, flexible strips of wood, plastic, or metal, called splines, which were held in place with lead weights, called ducks because of their resemblance to the feathered creature of the same name. The resulting curves were smooth, and varied in curvature depending on the position of the ducks. As computers were introduced into the design process, the physical properties of such splines were investigated so that they could be easily modelled. Specialized software have thus been developed (e.g. Rhinoceros, Maya, Catia, 3-d Max) to address, among other things, these issues.

Now, a twisted tower is an instance of a NURB (Non-Uniform, Rational, B-spline). A NURB could be a complex architectural object (building), a ship, an automobile, an airplane, a sailboat, etc. The underlying modelling of a NURB involves a mathematical technique using polynomials to describe smooth curves or surfaces. This technique was developed in the early 1970's as a method for creating smooth curves and surfaces interactively on the computer screen. A NURB is defined using vertex points, a knot vector, a polynomial degree, and one weight value per vertex point. The most identifying feature of a NURB is that the curve (or surface) does not pass through the defining vertex points. This means that a program that uses NURBs allows to edit the shape of a curve or surface by moving or dragging these vertex points. Since these vertex points do not lie on the curve or surface, the program usually connects the vertex (edit) points with straight lines. These lines are sometimes called the vertex mesh for NURB surfaces (Kolarevic, 2003).

In the present research, Rhino 4.0 has been used to undertake the modelling operation. Besides providing the tools to accurately model and document designs ready for rendering, animation, drafting, engineering and analysis, the software in question can translate NURB curves, surfaces and solids into forms that could be easily cut on laser machines, then later manufactured and constructed. The affordability, precision, short learning curve, speed and compatibility are attributes to be stressed alongside some specific modelling functions such "Contour" and "Unroll Surface." Since no existing software could meet the demands of every complex project, the interfaces between programs should therefore be highlighted (Franken, 2003). Files migrated back and forth between several platforms until the last stage of the modelling process.

The fabrication operation proper, conducted at our Advanced Digital Fabrication Lab, involves several steps. A 3-d digital model is first generated. The model is then twisted, "contoured" (sliced) and "smashed" (unrolled). The resulting layers, sections and unrolled elevations are then sent as 2-d files to a laser cutter to be cut, followed by an assembly operation that negotiates its success with the careful placement of all the components around a central core, at specific levels and with the right angular twist. The whole set of pieces is then assembled together.

The paper will present and debate the difficulties and challenges encountered in this process. Because the bulk of the present research deals with a precise technical exercise in fabrication, stress will be made solely on the technical steps involved, starting from the digital design to the final stage of the fabrication process. To start with, the 32 × 40m plan was imported as a dwg file. A central core was drawn in the middle, to be later used as a shaft supporting the several floors plates and elevations. The plan was next extruded to a height of 330m, using the "extrude surface" command. The tower is now a polysurface that is ready to be twisted (figure 3).

Figure 3. Digital model (wireframe), after being twisted.

The use of the "Persistent Osnap Dialogue" is also crucial, for it assists in making the precise selection of both the starting and the end of the axis of twisting. After correctly entering the start and end of the twisting axis, the system prompts the user to enter the angle of twisting, or to pick two reference points to define the rotation angle, which is 90 degrees in our case. Once the tower as polysurface has been twisted, the next step is to model the central core, which has to be extruded after the polysurface has been twisted, and not simultaneously. The rectangular/square shape will force the different plates to be locked in one specific position, corresponding to a precise angular coordinate, and thus inhibit their lose rotation around the axis.

Next, the contour curves and points are created from the intersections of a series of invisible parallel planes cutting through the selected object (figure 4). The contour command creates a spaced series of planar curves and points resulting from the intersection of defined cutting planes through curves, surfaces, polysurfaces or meshes. The first step here is the selection of the polysurface and core to be contoured. The second step is the picking of the base point; one of the contour planes will go through this point. Third, the system prompts the use to pick a direction perpendicular to the contour planes, which will be generated in both directions from the base point and will be perpendicular to the picked direction. Fourth, the system prompts the user to type the distance between contours (which is 3m in our case), then press enter. This will create contour curves where the contour planes intersect the selected surfaces and polysurfaces. One has to also make sure that the "GroupObjects-ByContourPlane" is set to "Yes." This will force all the segments forming a given floor to be joined to each other.

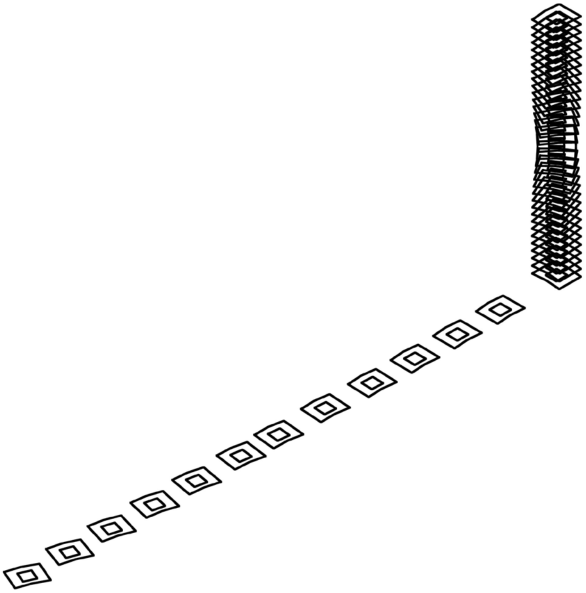

Figure 4. Some of extracted contour curves.

The still-highlighted contours have to be dragged away from the original polysurface for further manipulations. In the Front View, the lowest contour (corresponding to the ground floor) has to be dragged to the left, then the second contour, etc, until all the contours are distributed evenly in all the views. The use of Align command in the Top View is helpful. Unfortunately, the software used does not have a "distribute" command available on its menus (there are a couple of scripts online though); and so one has to try to do this manually.

The very useful command UnrollSrf flattens (develops) a surface or polysurface to a planar surface. When the Explode option is on, the resulting surfaces are not joined, which is convenient for later manipulations and laser cutting operations (figure 5).

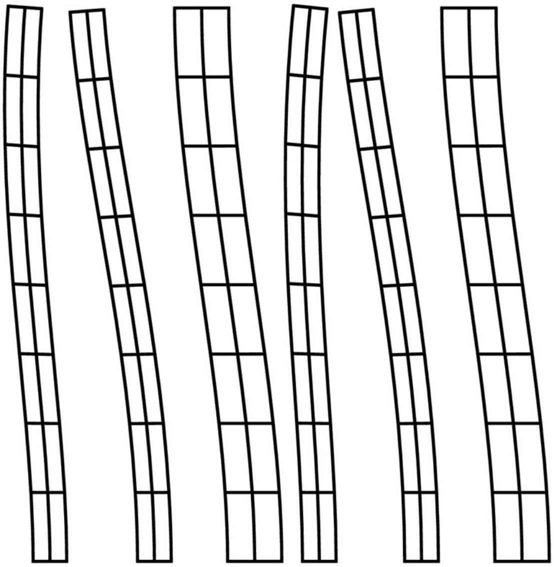

Figure 5. External surfaces unrolled.

The selected plans and elevations are next exported to AutoCAD, to be plotted at the desired scale. A mock up model should be next built to make sure that there are no mistakes in the conception of the floors and elevations. This crucial step is also justified by the fact it is easier and cheaper to test a model made from cardboard than from Perspex. Once the mock-up model is built, and that no mistakes are detected, the original plans and sections are sent to the laser machine to be cut. Depending on the model's scale, the thickness of the Perspex plates is determined. In general, the plates' thickness varies between 3mm and 6mm. The cladding material is cut from thin and malleable polycarbonate sheets, upon which vertical and horizontal lines are engraved so as to simulate fenestration patterns. The core around which the horizontal plates are to be placed is constructed from thick Perspex sheets. Because it also contains within it a miniaturized lighting fixture, special attention and care have to be paid to the detailing of this component. Also, because the stability and solidity of the whole model depends on it, the core should be firmly fastened attached to a wooden base with special bolts and screws. A thread maker is used to make the female thread in the model's core. Once the core is firmly fastened to its base, the floor plates are mounted, each at the right vertical level (figure 6).

Since we are here limited by space, only one final model is presented (figure 7). Out of the twelve models built so far, at different scales and using different cladding techniques, the model presented here is 165 cm high. The final presentation of the paper will exhibit other versions.

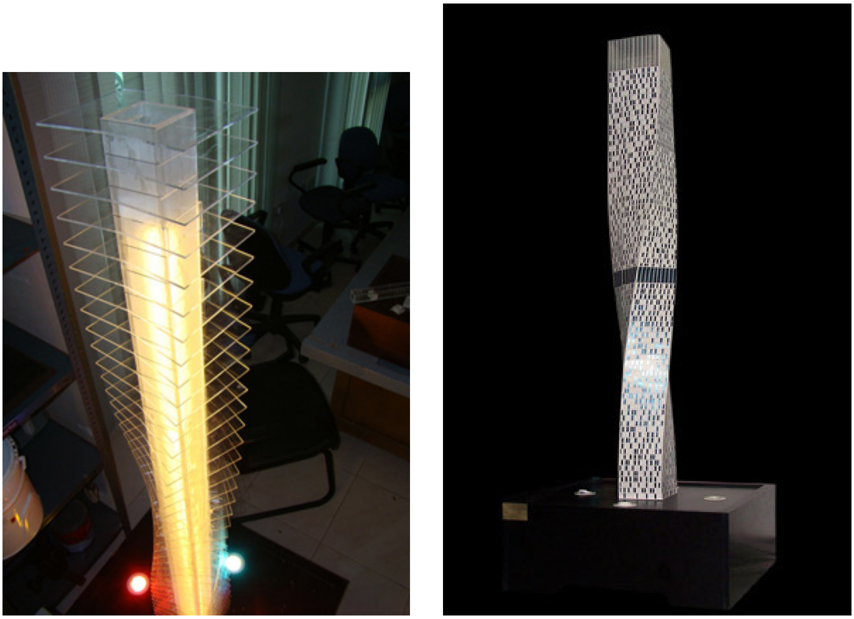

Figure 6 (left). Mounting of floor plates. Figure 7 (right). Final model (165 cm high).

3. Conclusion

It is finally pertinent to stress that the purpose underlying the writing of this paper is not to foster any design innovative intention, but to present a practical way to model one of the many architectural unusual forms that increasingly populate Dubai skyline, and which the architectural student, using traditional modelling techniques, often finds difficult to model and build at reduced scales. The process that is here described falls, therefore, within the pragmatic and not the theoretical or creative field of the architectural process. As such, it could easily be applied to the fabrication of any structure, no matter how complex and twisted it may be, as tested during the few last years in our digital fabrication lab. Based on this careful CNC/Laser-Cutting-Rapid-Prototyping orientation, other non-standard architectural objects have been modelled and built at various scales including planes, ships and motorcycles. Innovation here should rather be seen from a practical, and not a speculative, angle.

This orientation also means that the status of the architectural model is to be defined in terms of a convergence of particular technological possibilities, a fact tested through the making of a wide variety of prototypes, of which only one example has been particularly debated in the present article. This stress on fabrication allows a smooth and fluid dialogue between digital design and digital making at a reduced scale (Kenzari, 2006). One specific entailment of this is the fact that model-making is getting closer to the real act of building. For if we assume that the building industry will soon take advantage of the extensive capabilities of modelling-cutting techniques that have been, for example, exploited in the aeronautics/aerospace, automotive and shipbuilding industries, then it will be easy to see the closeness between the current making of an architectural model and the construction of a twisted building, for example. This closeness could be witnessed in terms of the technologies, the process of making itself, and the nature and application of the materials used. Alongside these similarities, there is also a convergence of the manual and the digital aspects of the making process. The meeting of cutting technologies and miniature tooling at the model-making level may not be exactly mirrored on the real construction site (for the problem of size and the typical nature of modelling and building, with all the empirical requirements embodied, stipulate different modes of constructing 3-D). And yet, the one level points clearly points at another, and one could easily tackle construction issues at a very reduced scale in this fashion, with all the empirical entailments involved.

Acknowledgements

This work was financially supported by the Research Affairs Council under a contract number 02-03-7-11/09, titled “Modeling Twisted Towers, using Dubai as a case study.”

References

Franken, B.: 2003, Real as data, *in* B. Kolarevic (ed.), *Architecture in the digital age: design and manufacturing,* Taylor and Francis, New York, 123–138.

Kenzari, B.: 2006, Physical modeling: the convergence of cutting-edge technologies and miniature tooling, *International journal of architectural computing,* **3**(4), 119–134.

Kolarevic, B.: 2003, Digital morphogenesis, *in* B. Kolarevic (ed.), *Architecture in the digital age: design and manufacturing,* Taylor and Francis, New York, 13–27.

Marrian, N.: 2008, Model makers benefit from growing real estate, *Gulf news,* 10 October 2008.

Moussawi, F., and Zeara Polo, A.: 2002, Roller-coaster construction, *in* N. Leach (ed.), *Designing for a digital world,* Wiley-Academy, West Sussex, 80–87.

Schneider, P.: 1996, NURB curves: a guide for the uninitiated, available from: Open Source Repository <http://www.mactech.com/articles/develop/issue_25/schneider.html> (accessed 4 November 2009).