

# Free-D High Rises

By Dr. Karel Vollers

*Integration of digital technologies into the various stages of building development rapidly increases the variety of high-rise volumes. A scheme has now been developed to classify the various building shapes. As shaping largely follows the modeling tools that architects have available, this scheme is based on those tools as well. Consequently, no knowledge of mathematical formulae is required to describe the complex curved façades. Transforming a shape is simple, but the structural consequences are considerable.*

## Modeling Software and High-Rise Shaping

Many non-orthogonal high-rises are designed to be iconic – to pinpoint urban projects, cities, regions, and even countries on the global map. Generally their façades are curved, or unusually shaped, for esthetic reasons, and sometimes to improve the building performance. Complexity of fabricating and constructing superstructures and façades, increases with the geometrical complexity. Remarkably, repetition of elements is losing importance. Various major projects demonstrate the economical feasibility of large-scale application of non-standard products. The relative ease by which one can now design, allows rapid shape development and quick generation of digital data on components and their production.

High-rise shaping is strongly related to the modeling tools that architects have available. Non-orthogonal building shapes traditionally are drawn by repeating floor surfaces upwards into a 3-D composition by applying the software commands Copy, Move and sometimes Rotate. Subsequently, façades are generated around the floors.



Figure 2a.



Figure 2c.



Figure 2b.

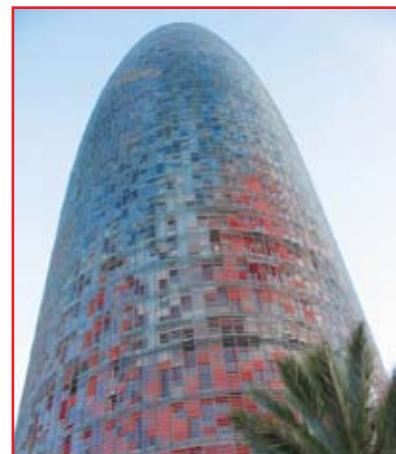
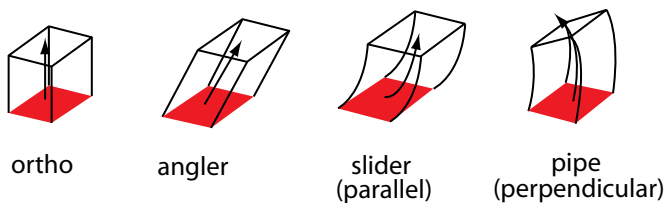


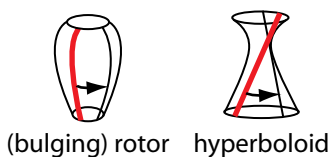
Figure 2d.

*Figures 2a, b, c, d - CCTV, Beijing (by OMA); Dancing Towers, Dubai (by Zaha Hadid); RAK Convention And Exhibition Centre Ras Al Khaimah, Dubai (by OMA); Torre Agbar, Barcelona (by Nouvel).*

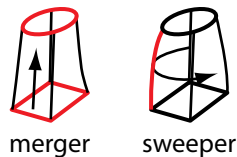
### EXTRUDERS



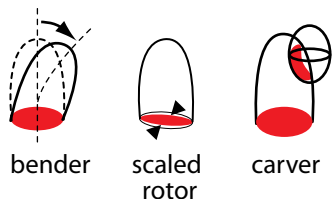
### ROTORS



### FREE-SHAPERS



### TRANSFORMERS



### TWISTERS

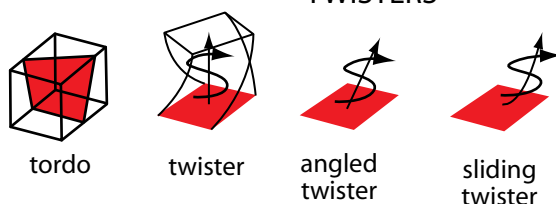


Figure 1: The CAD-tool shape scheme.

As shown in Figure 1, standardized shape names have been developed by the author to describe the specific groups and variations of shapes. For instance, building volumes with upward repetition of floors, without scaling or rotation, are called Extruders. Variations on the basic orthogonal volume are introduced by inclining the line along which floors are moved upwards and by bending the line. As the floors are multiplied upwards, a rotation can be added, turning the volume into a twister. The basic twister has a constant rotation around a vertical axis. Thus all floors stay identical and façades on each floor are repeated. Though repetition generally is advantageous, often now the rotation is varied and the volumes additionally are tapered. Such varying adds identity – and indicates that repetition of elements loses importance. Non-standard elements get affordable, owing to digitizing of all stages of building development. Rotors are generated by rotating a line around an axis. When axis and line both are vertical, a Cylinder results.

Free-shapers and Transformers are at the forefront of recent building developments. Data processing for form generation, and subsequently production, in recent years is eased by scripting or adopting parametric modeling procedures. In such software, shapes are described by relations between their composing elements. Some programs instantly provide data, such as on floor surface changes when, during the design, a building volume is bent sideways. The shapes described in the system can all be generated by parametric modeling. Transformers are volumes that have been transformed either as a whole, or in part. Carvers are sculpted by deducting or adding parts that are described by intersections with other parts.

In an Angler, identical floors are stacked under a fixed angle. An angler can consist of straight segments leaning in different directions (Figure 2a). When the inclination angle varies, or when built of straight segments interconnected by bent segments, it is called a Slider. Sliders can overlap to achieve a more rigid structure, shorten traffic routes and provide alternative fire-escapes. One of the Figure 2b sliders for stability in a corner rests on another slider. This additionally enables elevator shafts to vertically continue.

A Rotor is a building volume created by rotating a line around a vertical axis. When this line is a semi-circle with its ends on the axis, a Globe results. Holes are carved in the globe of Figure 2c. Rotational building models can be varied easily by manipulating the curve that is rotated. The Figure 2d tower seems a rotor, but is a Transformer with elliptical floor plans. Such a volume can be drawn with solid modeling software by first stretching a globe upwards and then squeezing it horizontally over one axis. Such transforming turns it into a Scaled rotor.

A twister has twisted façades that repeat on all floor levels (Figure 3a). The twisting superstructure in the façade of the Figure 3b twister has wide columns with vertical sides. They repeat upward, shifted sideways and maintaining an overlap. The zone between outer structure and flat recessed glass façades provides sunshaded balconies. The inward fold of one façade gives the tower an orientation.

As the number of façades around a twister grows, the shape resembles more a cylinder. This can allow for arranging a circle of vertical columns behind the façade. With vertical columns there is no torque on the structure. Tapering implies less vertical repetition, but this in Figure 3c and 3d twisters is compensated by horizontal repetition: 6 façades and 5 wings respectively.



Figure 3a.



Figure 3b.



Figure 3c.

Figures 3a, b, c, d, e - Turning Torso, Malmö (by Calatrava); Infinity Tower, Dubai (by SOM); Fordham Spire, Chicago (by Calatrava); Gazprom, Petersburg (by RMJM); Ocean Heights One Residential Tower, Dubai (by Aedes).



Figure 3d.



Figure 3e.

A tordo is a transformed volume, with at least one corner moved out from the orthogonal structural grid. It thus has one or more twisted façades. The mullions of the Figure 3e tordo connect to parallel vertical structural walls. All components of the twisted façades are different.

Freely curved glass panes have as yet not been produced on a scale fit for high-rise. Therefore, twisted surfaces were replaced by cylindrical surfaces or were tessellated (by approximating the curving shape with flat triangular panes). Just like the underside of a set of stairs, a twisted surface can be approximated by flat vertical and horizontal surfaces. Stepped twisters are built of stepped flat façades. The Figure 4a Stepped hybrid twister has stepped surfaces that connect around a cylinder.

When floors are moved upwards and sideways, along a curving axis, a Slider results. By adding a rotation, it becomes a Sliding twister. When the 3D axis is a helix, the volume is named a Helical twister. Helical twisters can adjoin, intersect or merge, depending on their positioning and proportions (Figure 4b).

Overlapping can provide a vertical zone for elevator shafts. The Dubai Towers (Figure 4c) are Tapered sliding twisters. Their floor plans scale down, while moving upward and rotating along a double curved axis. This curvature of the axis is varying, and chosen such to result in pleasingly curved façade contours. The vertical structural cores stay within the octagonal floor plates. Where floors are very eccentric to the core, high atria are made to reduce structural loads.



Figure 4a.



Figure 4b.



Figure 4c.

Figures 4a, b, c - Mode Gakuen Spiral Tower, Nagoya (by Nikken Sekkei); Cobra Towers, Kuwait; Dubai Towers, Dubai (by TVS).

continued on next page



Figure 5a.



Figure 5b.



Figure 5c.

The increasing use of non-standard elements in twisted facades implies that such geometry is not applied for economic gain by repetition, but for ease of construction. While twisted façades are double curved, the straight floor ends and façade transoms are easier to measure and realize than curved elements would be. The repetition of lines on such shapes helps understanding the geometrical build-up. The inclining contours add a notion of movement to the shape – depending on the degree of rotation, torquing associates with slow and lazy, to painful and strangling.

When the sequence of applied manipulations is not obvious, the volume is called a Free shaper (*Figure 5a*). The sinuous balustrades and louvers of the *Figure 5b* buildings are single-curved. Buildings with protruding elements that make the façades seem double curved, are classified in the special category Slicers. *Figure 5c* shows a canyon-like cut-out. The freely curving façade juxtaposes the box-like overall shape.

*Figures 5a, b, c - Tour Phare, Paris (by Morphosis); Slinky Twins, Paris (by PCA); Opus, Dubai (by Zaha Hadid).*

The glass industry has for many years been lagging behind in developing production facilities for such glass. If this project is executed with freely curving insulated glass panes, it will be a major breakthrough.

With architects getting accustomed to software modeling tools, new shapes are emerging. All pictured buildings in this article, except maybe the Cobra Towers, are in the process of being built, or are finished. They are a minor part of what is being realized globally. Many more will arise when freely curved panes become more affordable.

Development of production facilities for freely curved glass is speeding up. An aluminum curtain wall framing system for such façades is available: the Alcoa/Kawneer AA100Q-Twist system.

Education on the geometrical aspects of complex geometry buildings is highly eased by the recently published book *Architectural Geometry* (Pottman, et al). It elaborates in a very accessible way on the various topics that architects and product designers come across when modeling on their computer. The CAD-tool shape scheme connects to the descriptions and names used in the book. A few years ago, many shapes described in the scheme would have seemed mere theoretical – now many have been built, and in variations. New modeling tools and new computer based structural calculations will bring new shaping of high-rises. ■

*Images Courtesy of OMA, Zaha Hadid Architects, HSB/Calatrava, SOM, ADS Studio, RMJM, Aedes, Nikken Sekkei, Brian Gassell/TVS, Morphosis, and PCA Architects.*



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## References

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