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Karel Vollers is developer of an aluminium framing system for twisted façades with Alcoa Architectural Systems. In 2001, he earned a Ph.D. cum laude at Delft Faculty of Architecture and won the Dutch Aluminum Prize for Architecture.

Since then, he has led the Blob Group at the Department of Product Development, Faculty of Architecture, a group consisting of graduates, promovendi, and researchers who develop new techniques for materializing double-curved façades. Dr. Vollers has been an invited speaker and presented papers at many congresses all over the world. Recently, he produced a new framing system prototype with Alcoa which included both freely double-curved glass and an opening window. They both are worldwide primeurs.

High-Rise Buildings with Twisted Façades

Increasingly, high-rise buildings feature twisted façades. Often such buildings are intended to become icons and give identity to major urban schemes and the cities where they are (to be) built. Many well-known architects made spectacular plans. Initially classed as visionary, the projects since 1990 increasingly appeared in competitions and feasibility studies all over the world. Now the first have been built.

This presentation will classify types of buildings with twisted surfaces and illustrates their usage in high-rise towers. Various aspects are elaborated on: geometric manipulations (for example repetition and mirroring of volumes), semiotic connotations (for example connected with the rotation direction), and construction (structural principles and façade grids).
High-rise Buildings with Twisted Façades

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Abstract (revised)
Increasingly high-rise buildings feature twisted façades. Often such buildings are intended to become icons and give identity to major urban schemes and the cities where they are (to be) built. Many well-known architects made spectacular plans. Initially classed as visionary, the projects since 1990 increasingly appeared in competitions and feasibility studies all over the world. Now the first have been built. The author classifies buildings shapes with twisted surfaces and illustrates their usage in high-rise. Various aspects are elaborated on: geometric manipulations, visual aspects and the increasing interest in the use of façade diagrids.

Landmarks with twisted façades

Fig 1a: Turning Torso in Malmö, by S. Calatrava, –2005
Fig.1b: 150m high twister in Amsterdam-Z.O., (unbuilt), by K. Vollers with Pi de Bruijn, 1998
Fig.1c: U2 tower on riverside in Dublin, by Craig Henry Architects with BDA, 2002-
Fig.1d: Twister at Milano Fair, 2004-, by D. Libeskind c.s.
Fig.1e: ECB in Frankfurt, by Coop Himmelb(l)au, 2005-

Increasingly high-rise buildings feature twisted façades. Often such buildings with their uncommon overall shapes are intended to become icons and give identity to urban schemes and even cities as a whole. Many well-known architects designed spectacular projects with twisted surfaces. Initially classed as visionary statements, the plans since 1990 increasingly appeared in competitions and feasibility studies all over the world. Now the first have been built. The 190m high Turning Torso tower designed by Calatrava, in 2005 was inaugurated. It is a new landmark in the redeveloped former shipping industry area of Malmö (Sweden). It has no built precedent. The 90º twisted tower obtains stability from a central cylindrical concrete core. Most of the weight of the concrete floors rests on the core; the steel exterior profiles are mainly decorative. It has a mixed use: lower floors are offices, the upper apartments.

The author in 1998 designed with Pi de Bruijn a 150m high focuspoint in the new office area Amsterdam-Z.O. The upper end of the twisted volume aligns with the orthogonal street grid of the neighbourhood, whereas the façade at the bottom end lies parallel to a boulevard that diagonally crosses the grid. It exemplifies the use of twisted shapes to create a visual relation between directions in an urban plan. The two intersecting volumes are elaborated as four identical wings hanging from a cylindrical concrete core that houses the vertical ducts, stairs, elevators and services. This structural
concept, designed by ABT engineers, evades incremental torsion forces by the buildings’ own weight resting on inclined façade columns. The identical wings feature a considerable recurrence of elements. The planned use of cold bent glass panes, would have approximated fluently twisted surfaces with negligible tolerances.

Craig Henry Architects in conjunction with BDA won the competition for the new headquarters of music band U2 in Dublin (Ireland) with the design of a moderately twisted tower. Its height and the degree of twisting is still being worked on. It will be a visual focuspoint in the harbour redevelopment.

Daniel Libeskind, in collaboration with Zaha Hadid, Arata Isozaki and Pier Paolo Maggiora, in 2004 was announced winner of the Fiera Milano redevelopment competition in Milano (Italy). One of the spectacularly shaped projected towers is tubular around which a pointed wing twists approx. 45°. The grid of emphasized diagonals on the façade widens to the top.

The competition for a new European Central Bank building in Frankfurt (Germany) in 2004 was won by Coop Himmelb(l)au. Two different twisters are connected by a De-Constructivist composition of bridges, floors and structural beams.

All above designs combine new technical achievements with new shaping. CAD, CAM and CAE play a major role. The transforming technology of glass panes as yet is lagging behind.

Twisters and Tordos

Fig. 2a: Twister
Fig. 2b: Non-orthogonal superstructure with façade connecting along straight lines to floors
Fig. 2c: Tordo
Fig. 2d: Orthogonal superstructure with façade connecting along straight lines to walls and floors

Buildings with twisted surfaces can be classified in Tordos and Twisters. Both names were assigned to the types by the author.

* A Tordo is a building with one or more twisted façades connected to an orthogonal superstructure (= a rectangular structural grid). The floors are basically repeated in vertical direction, with interior walls and columns aligned. The twisted façades of a Tordo at one or more sides introduce floor endings that don’t parallel the orthogonal grid of the building. A rectangular floorplan in a Tordo is an exception in the sequence of floors. The rotation axis of the twisted surface usually lies in the façade. All elements in a Tordo’s twisted façade are different – in upright and in horizontal direction.

* A Twister is a building with floors that lie horizontally rotated around a vertical axis. This axis usually lies in the centre of the floor plan. Often there is a cylindrical core, around which floorwings lie. The structural members, mullions and contours all circle helically upward around the rotation axis, resulting in a non-orthogonal superstructure. In a simple Twister all floors are identical and rectangular; they are positioned with a fixed incremental rotation. Some structural elements (like cores with elevators) may be aligned in vertical direction, close to the axis of rotation, but basically interior walls are not aligned with the ones of the floors above or under. Most Twisters liken because of the helices in the façades. In a Twister all elements in standing direction are similar when the degree of rotation per floor is constant. Horizontally neighboring elements in a Twister differ.

The multitude of component sizes in twisted surfaces implies high costs in production, assemblage and logistics. Though in a high-rise Tordo many façade elements may be standardized (within acceptable tolerances), a Twister will have greater recurrence of elements.

The helical mullions of a Twister incline both sideways and in or outward. This greatly complicates the connection to inner walls. These walls are often necessary, to comply with sound and smoke regulations. In a large Twister the twisting per element is small, and the inclination of mullions too. Therefore a wall-façade connection in a high-rise twister is relatively easy to make. The connection becomes more complex when the torsion is big, which often is the case in small buildings. Tordo’s
have the major advantage that usually a type of twisting is chosen in which their mullions lie in parallel vertical surfaces that align with the walls. Those mullions don’t incline sideways.

**Concise historical perspective of Twisters**

Numerous Twister shapes have been designed. The common parameters to vary on are: shape of floor, direction and degree of rotation and the scaling of floor plans in 1 or 2 directions. Variations may also be made by combining volumes. The additional volumes may be twisted too, and be generated by copying, mirroring or applying the complementary shape of the original. The volumes can interconnect in a point, along a line or intersect. Also different kinds of volume types, like cylindrical and twisted, may be combined, their surfaces meeting along a helical line.

In time, twister designs feature an increasing volumetric complexity, related to technical developments.

![Image 1](image1.jpg)

Fig 3ab: office building Leningradskaja Pravda Moscow, 1924 (unbuilt), by Konstantin Melnikov

Fig 3c: Perspective of apartment buildings Roof and Penthouse in Sao Paulo (Brazil), -1978

Though twisted concrete surfaces are relatively easy to construct, until recently transforming glass especially, was economically unfeasible. A twisted overall shape, without twisted surfaces, can be made by connecting units along a cylindrical core. In 1924 the Russian Constructivist Konstantin Melnikov designed the office building Pravda Leningradskaja. The floors of this steel structure hinge around a steel core; terrace surfaces vary along with the volumes and stairs rotating over them. Constructed in 1978, the towers Penthouse and Roof lie along the Giovani Gronchi Avenue in the traditional Morumbi neighborhood in Sao Paulo (Brazil). The apartment buildings have one apartment of at least 490 m2 per floor. Each building has a concrete cylindrical core from which units hang with a room extension with balcony. Each balcony has a swimming pool. The buildings were designed by Adolpho Lindenberg (born 1924, in São Paulo) and built by Construtora Adolpho Lindenberg S/A.

![Image 2](image2.jpg)

![Image 3](image3.jpg)

Fig. 4a: Helix City, plan for Tokyo, by Noriaki Kurokawa, 1961

Fig. 4b: Helical Skyscraper, by Manfredo Nicoletti, 1971

Fig. 4c: 400m high tower, by Thornton and Weese, 1980

In 1961 Noriaki Kurokawa designed Helix City, a visionary project for Tokyo with twisted overall shapes, but with on the floors a mix of orthogonal volumes. He proposed many variations on twisters.
with a central vertical axis of rotation: adjoining 90° mirrored twisters, intersecting twisters and twisters with additional stabilising walls. By adjoining contrary rotating building volumes he balanced torsion forces.

In 1971 Manfredo Nicoletti designed the Helical Skyscraper. Three twisted volumes each twist at one end around a vertical axis. The tapering shapes meet at the top in a triangle. Taking the tallest and most efficient structures in the world, guyed broadcasting towers, as an inspiration for buildings in the super tall range, Charles H. Thornton, of Lev Zetlin Associates in New York, in 1980 designed a twister with architect Harry Weese. The outer columns imitate the action of guy lines, pulling the tower back to the vertical when it tries to sway in any direction. This way the guys need no anchoring. The ground plans of the twister (400m in height) rotate 45° around a vertical axis. The side contours are helical. In a subsequent design the floor layout was changed: the top was reduced in size to decrease windage.

Subsequent designs surpassed the problems how to make twisted glass panes and approximated a perfect twisted façade surface with flat panes. In the High-Rise Module designing course, led by Professor Berenbak of the Faculty of Architecture of Delft University of Technology, since 1991 a number of student teams designed and elaborated various towers with twisted façades. Subsequent twisters varied on degree of twisting, scaling of floor plan and construction system.

The ‘contrary’ inclining position of the columns and the bevelled top are distinctive for the 70° twisting Weena tower designed in the 1991High-Rise Module workshop. The steel structure has a central cylindrical core. By the heeling façade columns the torsion forces will be for a great deal compensated. The inclined roof adds individuality to the shape and introduces a new direction. The zigzagging Tower 1.2 (1993) decreases torsion forces on the core by alternating the rotation direction. The Spiral Tower (1993) reduces torsion forces by tapering the volumes to the top.

The USTRA twister (-1995) designed by Frank Gehry has a rotation axis at one of its corners. All façades are different. The flat windows lie recessed in walls rendered flush by plastering.
By adjoining volumes, structural stability of high-rise with a slim aspect can be achieved. In the Spin tower designed in the 1998 High-Rise Workshop, two volumes with triangular floors are interconnected. The two twisting volumes of the A-tower (2004) in width decrease to the top. The Jinling Tower (2003) accommodates a six-star hotel, class-A office space and luxury apartments. This competition entry by Skidmore Owings & Merrill (not won), aims at creating a landmark tower for Nanjing, China. The tower is composed of four overlapping twisted volumes that rotate 90°. The overall ground floor and roof plan are square. The floorplans shift to an ‘x’ in the middle levels, making the building expose there more perimeter surface. The tower is a hybrid of Twister and Tordo: the four quadrants are twisters, but the centre with overlapping twister sections is orthogonal.

The Guardia Airport Traffic Control Tower in New York by Voorsanger & Associates (1999) features four twisted façades. The top ends of the volumes have been cut of at the corners, resulting in octagonal roofplans of which total width and depths are similar to the bottom ends. The High-Rise tower (2004) has a triangular glass façade at a corner too. Of the overall twisted triangular volume, one façade obtained an extra twist, thus splitting open along one cornerline. The tapering 610 m high Fordham Spire that S. Calatrava proposed for Chicago (2005) is a twister with a square floorplan that scales down to the roof. From the ground floor upward the corners have incrementally been cut of; the widening corner surfaces meet as a round roofplan.
Concise perspective of Tordos

Fig. 8a: Type 1, with straight lines in horizontal and in parallel vertical surfaces
Fig. 8b: Type 2, with one curved side and straight lines in parallel surfaces
Fig. 8c: Type 3, with 2 curved sides and straight lines in parallel surfaces
Fig. 8d: Type 4, with 2 contrary curving sides and straight lines in parallel surfaces

A Tordo is a building with an orthogonal structure and one or more twisted surfaces. Tordos connect with their straight lines to an orthogonal grid that usually corresponds with the walls and floors. They are easy to define because the horizontal lines have a constant height, e.g. a parapet edge or a connection to the floor structure. The upright rules connect to columns or walls. A tordo may have a combination of different kinds of twisted façade surfaces, that connect with straight lines to walls and/or floors.

Fig. 9a: Building complex in Amsterdam by Fenna Haaksma Wagenaar, 1998
Fig. 9b: Marina Mandarin Hotel in Singapore by Kevin Roche, 1987

The great advantage of a twisted surface in a Tordo is that the mullions connects to the building in a relatively conventional way. They only heel in or outward and not additionally sideways like in a Twister, simplifying the connection to inner walls considerably. However, as most façade components basically are all different, the manufacturing, logistics and assemblage require high level CAD-CAM processing.

F. Haaksma Wagenaar for her Master Study designed a Tordo with a high open inner court in a plan for Amsterdam (1998). The Marina Mandarin Hotel in Singapore designed by Kevin Roche, is composed of two twisted volumes that encloses a 21-storey atrium. The guest rooms open up to corridors looking over a foyer in the atrium. The upright rules of the outer façades connect to the orthogonal superstructure. The façade is composed of flat building elements.
The 2001 design by SOM of the Freedom Tower would have been an exemplary Tordo. It however in 2005 was replaced by a design with only flat surfaces. Two twisted façades were to run up from ground level to a staggering 590m. The grid over the façade had a glass infill of four-faced pyramids. The parallelogram ground floor with its sides linked up with the streetgrid.

**Triangulation and diagrids**

Increasingly towers feature casing diagrids with diagonal members and no columns in between. Forerunners of such diagrids were the hyperboloid tower structures, that Suchov used for the Current Poles to the Oka in 1927. The straight columns provide great structural stability. In time several hyperboloid buildings were proposed. I.M. Pei in 1956 designed an Office Tower for Grand Central in New York. The whole building is wrapped in a twisted diagonal mesh with intersections at regular intervals. Recent similar projects are the Il Diavolo tower by the Delft High-Rise Module (1999), the Vortex Tower in London by Ken Shuttleworth (2004) and the Tornado Tower in Munich by SIAT (2005). The diagonals heel much less than in conventional diagrids where inclinations are between 30° and 60°. In Pei’s tower the diagonals intersected on twisted façades. They crossed on flat façade surfaces a few decades later in the Russia Tower project in Moscow, designed by SOM in 1992, and on both flat and twisted façades in their 2001 Freedom Tower design. (SOM presented a complete redesign with a different façade structure in 2005). An indication of the growing interest in the use of only diagonals, was that in the revised edition of 1997 drawings of them in trussed bays and trussed casing systems were added to the chapter on high-rise of *Structure Systems* by Heino Engel.
More extreme triangulation has since appeared in many high-rise projects as an externally visible means of constructing. The usage in tower proposals coincides with a new appreciation in architecture of diagonal structural façade members. Nowadays it often not only is appreciated as a distinguishing dynamic feature on the exterior, but in the interior also. Transforming a triangular grid to approximate a doublecurved surface with flat surfaces, is common practise. Flat surfaces are cheaper to produce than doublecurved surfaces. Examples are numerous: the geodetic domes designed by Buckminster Fuller, or recently, the Swiss Re tower designed by Foster and Associates (-2001).

In a high-rise, the openings between diagonals of only slight inclination, are so wide that a mesh of mullions will be made to hold the glass. Preferably these lie in parallel vertical surfaces that enable straight connections to the walls. In a twisted façade, the diamonds will be twisted too, implying their infill must be triangulated to encase the flat glass panels. This can be used to add texture to the façade. Apparently as yet diagrids with almost upright diagonals were applied only in designs of buildings.

Distant views of buildings with twisted surfaces

Fig. 11ab: 60m perspective and isometric view of twister with eccentric axis, by K. Vollers, 1994
Fig. 11c: 150m twister with two intersecting volumes, by K. Vollers and Pi de Bruijn, 1998
Fig. 11d: Freedom Tower, by SOM, 2001
Fig. 11e: Shanghai World Financial Centre, by KPF Associates, 2003-2007

Architecturally it is interesting to create contours of different curvatures, as this implies an interaction of their different semiotic meanings. This can be achieved by placing the axis of a Twister eccentric, like in the 60m Twister designed by author. There all contours differ. However, difference in contour curvature of a high-rise building is harder to see, if at all, because of increase of radii. Often curved contours and surfaces lead to interesting 2D graphic pictures with unexpected visual effects. Specific viewing points are chosen to emphasize its special features. Sometimes this representation becomes an iconic image. In high-rise, curved surfaces are an outstanding feature. Therefore in distant views those pictures are chosen that depict this quality. Inclined contours or lines across the surface are unusual. Here a straight line draws attention, but a curvature even more. The bigger the curvature, the stronger the indication that there is at least one curved façade, giving the building an unusual quality. However, a 2D picture has in common with a distant view the loss of perspective and therewith insight in 3D shaping. The geometry of a building with curved surfaces from a distance is hard to define. The skyline of towers stands out clearly. But corner lines as a contour may often be confused with surface contours that come with the surface curvature. It is similar to a picture of a ball: the ball has no corner lines, but does have curved contours. They may be called surface contours.

A Twister and a Tordo both have twisted façades, but their overall shapes are very different. Some of their perspective views resemble, but these also liken buildings without twisted façades. With the curving cornerline across the image, the shape of the Shanghai World Financial Centre, 2003-2007 by KPF Associates, resembles a Twister. But it's surfaces are flat and singlecurved. A surface on a Twister does not like a flat or cylindrical surface have 2 vanishing points on the horizon to which all horizontals point. Every straight line on a twisted surface has its own vanishing points. By emphasizing the lines, for example by aligning mullions or transoms, the physical shape of the building is easier to recognize.
Conclusions
1 The most common types of high-rise buildings with twisted façades can be classed in two types: twister, with repeating rectangular floorplans rotated around a vertical rotation axis, and tordo, with one or more twisted façades that connect with the surface rules to the orthogonal superstructure.
2 The use of twisters will increase, as the repetition of structural and façade components makes their doublecurved façades economical feasible.

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