An increasing number of architects are being inspired by smooth curves and surfaces. Drawing them is one thing, but actually building them is quite another. When flat window panes protrude from the facade, they rudely interrupt the free flow of the design, according to Dr Ir Karel Vollers of the Faculty of Architecture of Delft University. That is why he is launching a worldwide first: a prototype of a freely curving, convex window, complete with frame, courtesy of intensive collaboration with leading glass and aluminium manufacturers. As a bonus the new design offers easy connections to existing building structures, an aspect that used to be a considerable problem. On top of that, Vollers has taken into consideration the feasibility of producing such high-tech windows at an affordable price. His design has been patented.
“Ever since the nineteen eighties, architects in Holland and abroad felt dissatisfied with the ubiquitous rectangular blocks of buildings, more often than not clad in a plate-glass curtain wall,” says Vollers, who is an architect as well as a building technologist. “So they started experimenting with cylindrically rounded buildings, and eventually started sketching voluputous curves inspired by images from nature such as dunes, beaches, waves, and the images of information streams flowing around the Web.”

Having graduated as an architect from TU Delft, Vollers worked for various architects’ firms as a project manager. Following an intermezzo as a designer and wholesaler of light-emitting jewellery, he embarked on an eight-year doctorate research project. In 2001 he was awarded his doctorate at TU Delft with a cum laude distinction for his thesis, Twist & Build, creating non-orthogonal architecture. He has since been working as a lecturer at TU Delft, and in addition runs his own architect’s firm in Amsterdam.

Freedom of Form “Of course, rectangular buildings are less complex to produce, measure, and assemble,” Vollers says, “which is why they are cheaper. These days however, architects like to take inspiration from flowing lines; they are searching for much more freedom of form.” For this reason Vollers is collaborating with glass and aluminium manufacturers to produce a freely curving façade system.

“However, their production must be financially feasible,” Vollers says. “We’re not simply looking at one-off prestige objects like exhibition pavilions or upmarket company office lobbies. We want it to be a commercially viable system. You could build council houses with nicely curving bay windows or skylights! With an equal outer surface it can offer much more extra space and volume than a rectangular box ever could!”

During his research Vollers had to translate architectural designs with curved lines, twisted surfaces, and flowing shapes into structurally feasible models. He developed a sample sheet of different building shapes with curved façades. The freely curved ones are classified as BLOB, a reference to the shapeless, mangle-eating, gelatinous monster in the film of the same name (USA 1958, directed by Irvin S. Yeaworth, with a remake in 1988). In mathematics, BLOB also stands for Binary Large Object, i.e. a cloud of data. At the Delft Faculty of Architecture, Vollers heads the BLOB group, which, supervised by Prof. Dr Ir. Mick Eekhout, looks at how these challenging buildings can materialise.

“Non-standard architecture covers about the same field,” Vollers says, “with different parts all being different shapes. Non-standard emphasises the lack of repetition of parts, as yet they usually are straight or flat; BLOB underlines the free-flowing nature of these shapes and their components.”

When building a BLOB, the major technological challenge is to create highly twisted window frames in extreme structures, not to mention the glass that goes in them.

Vollers classified various (building) volumes according to their geometric features.

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<tr>
<th>Extruders</th>
<th>1 Ortho drawn by shifting ground plans along a vertical line</th>
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<td></td>
<td>2 Angler ditto, along an inclined straight line</td>
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<td>3 Slider ditto, along a 2D curve</td>
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<td>Rulers</td>
<td>4 Free ruler with ruled surfaces (conoid and hypar)</td>
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<td></td>
<td>5 Ortho-ruler ditto, of which some connect with their rules to an orthogonal grid</td>
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<td>6 Free-conoid one or more conoids, of which at least one doesn't connect with rules to an orthogonal grid</td>
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<td>7 Ortho-conoid ditto, of which all connect with rules to an orthogonal grid</td>
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<td>8 Free hypar one or more hypars of which at least one does not connect with rules to an orthogonal grid</td>
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<td>9 Tordo one or more hypars, of which all connect with rules to an orthogonal grid</td>
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<td>Twisters</td>
<td>10 Twisters a repetition of twisted façade elements in vertical direction</td>
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<td></td>
<td>11 Roto-Twisters a repetition of twisted façade elements in horizontal direction, while floor plans differ on each level</td>
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Sectional Aluminium

To fit the curved glass, the glazing supports must be twisted. This can be done in a number of different ways. Vollers, together with the Alcoa Architecturysystemen company, aluminium façade system designers, opted for a simple and cheap solution, which was to redesign an existing framing system. The design has been exhibited at international conferences from Helsinki to Seoul, and the researcher has taken out a patent on it. In 2001 Vollers was awarded the Dutch Aluminium Award for Architecture. The Alcoa AA100Q-Twist facade system has been developed specifically for the creation of free-form curved façades. The use of new techniques has made it possible to simultaneously bend and twist the framing profiles and so achieve the variable curvature of the design’s surface. The system includes a window that opens smoothly and that features a multi-point latching system. The axes of the hinges (halfway along the top and bottom bars of the window) are exactly in line.

A major advantage of starting out with existing components such as glazing bars, joints, metal strips, and rubber seals for the Twist facade system, is that the current certificates can be used.

Vollers: “The system is unique because it enables us to make curved surfaces that are much more complex than simple cylinders and cones. Once a glass facade can be curved, the industry will be quick to transform other elements accordingly. There is a whole new field of components waiting to be developed by the industry.” Vollers himself will now focus on the development of freely double-curved toughened glass.

“For continued innovation it is essential that glass producers and window frame manufacturers work in concert, because the one cannot exist without the other. So far we have been unable to produce the curved glass cheap enough, and as long as that does not succeed, the suppliers of building components that connect with the window frame will not develop their product. In other words, stalemate.”

So, different industries will have to start investing in the new technology at the same time. Vollers: “There is no market demand yet, since the product is still completely new, and still at the development stage. The computer-controlled mould system has not yet been built either. Now that a few builders have spent a lot of their energy on complex, labour-intensive projects, the industry is sitting back to watch what comes next. Developments don’t wait however, and building processes are becoming more rational, and will soon fit building practice. I expect our new facade system to be used on a large scale within five years. We will soon be flooded by new construction projects.”
Bendable

Vollers is now making headway with an improved prototype of the façade system which he developed together with aluminium manufacturer Alcoa Architectuursystemen bv. The system can seamlessly attach any shape of freely curving glass surface to buildings with any structural grid. Usually this is a rectangular structure, in other words, vertical walls, horizontal floors, and rectangular floor plans.

Vollers: “If you design a freely curving curtain wall around such an orthogonal building, you run into the problem that the window frames do not meet the floors and the interior walls at right angles. The angle changes constantly, and the glazing supports must be capable of accommodating the change. With the façade bending forwards and backwards, it has to support structural forces, show and wind loading. These window frames are subject to considerable stresses.”

The frame consists of two parts. The rear, rigid support profile can be fixed parallel with or at right angles to a flat wall or floor, and absorbs all the forces. A specially designed glazing strip is used to fit the curved glass. It rotates around the cylindrical edge of the rear support.

“The very bendable glazing strip can be shaped and fitted on site during construction,” Vollers explains. “I think our design may be the key to a rational execution of freely curving buildings.”

For the prototype the glass is shaped onto moulds that have been milled from aerated concrete. The resulting shapes are of very high quality, with a much more evenly curved surface than obtained with earlier prototypes. A new addition to the façade system is a window that opens and closes very smoothly.

“I’m looking forward to tackling the first large-scale project with the new system”, Vollers continues. “It will be far from simple. With all the windows being different shapes, the panels must be very closely matched in all three dimensions, and they must be fitted together at exactly the right angles. Computers play a major role in this process, which is ten times more complicated than fitting a normal, flat curtain wall.”

The power of Niemeyer

The history of the project goes back a long way. One source of inspiration for Vollers is the oeuvre of Oscar Niemeyer (b. 1907), examples of whose work he first saw in 1986 during an architects’ study tour through Brazil.

“Niemeyer is the main architect of the new Brazilian capital, for which he used a work force of 50,000. The power of his form language was a revelation to me. His buildings stand in the landscape like sculptures, and in some cases they connect with it. The contour of the new museum of modern arts, MAC, at Niteroi, Rio
Janeiro, for example, very cunningly runs parallel with the contour of Sugar Loaf Mountain in the background. I think that is great.”

Niemeyer accepted commissions from all sorts of totalitarian regimes. “His philosophy is that as time passes, the circumstances under [?] which buildings were built, disappear in the background. What is left is the building. Good and grand designs can lift people out of the misery and poverty of their daily lives and so make them feel better. His designs manage to make people marvel, which is a very generous gift, and I like that.”

Niemeyer managed to build his labour-intensive designs in South America with optimum use of low wage levels. Vollers has pinned his hope on computer power. “A computer can make hard work light.”

**Systematic Description**  During his research, Vollers started a systematic description of the form and material properties of a twisted façade. Vollers: “You cannot bend a twisted surface from a sheet of paper, since the surface has to be stretched. Similarly, you cannot make the outer surface of a ball from a sheet of paper either.”

The straight lines in a twisted surface, don’t run parallel with each other, nor do they pass through a single point, as in a cone. He replaced the mathematical plane descriptions and formulae with an inventory of shapes of his own that is geared to actually constructing it rather than understanding the mathematical ins and outs. For example, he describes a twisted plane as ‘a plan constructed of straight lines that are formed by copying a line and then translating and rotating the copied line. It always involves a rotation at right angles to the translation. “There is no mathematics involved,” the researcher emphasises. He used this method to describe a whole range of complex building models, and then analysed each for its external appearance, construction, and possible façade connections. Eventually, he arrived at two main types, the ‘tordo’ and the ‘twister. A tordo is a building that incorporates at least one twisted façade, and that has a rectangular supporting structure. A twister is a building all the façades of which twist in the same direction, like pasta twists. Each floor of a twister is slightly rotated relative to the one below. A fine example of a twister is the 180 m high Turning Torso tower at Malmö, designed by Calatrava.

Having finished his research, Vollers focussed on the construction of free-form, or freely double-curved planes. “These basically do not feature straight lines and therefore are much more complex. This puts up the price of construction, but on the other hand an architect gets much more power of expression in return,” Vollers says. “Creating a building with playful, free forms as yet requires a lot of manual labour. As a result you only see few of them. Their rarity gives the buildings an aura of luxury, if only because so few people can afford one. But these buildings will now be constructed in greater numbers, and computers will take over much of the work. Even the manufacture of exclusive glass and window frames is becoming automated. Masters such as the American architect Frank Gehry have a fantastic team of computer experts at their disposal. They know how to get the most out of the available production options when working on their dream forms.”

**Liberating**  Free-flowing shapes may be used to set a design in its urban or landscaped environment. For instance, the baseline of a façade can take on the direction of a nearby object such as a road or a canal while the top of the façade echoes a quite different direction; within the surface plane they twist towards each other.

“Architecturally speaking, a twist in a form or surface has an alienating effect,” Vollers says. “The perception of the perspective is different from that of a normal rectangular building, because instead of a single vanishing point there is a whole series of them, one for each horizontal line in the façade.”

Until now, architects building such a curved shape with glass could only approximate it by faceting the surface, i.e. breaking up the façade in lots of small flat surfaces.

“A good architect manages to turn constructional limitations to his advantage,” Vollers says. A faceted diamond is more attractive than a rounded one. Likewise, a façade can achieve crystalline beauty.”

However, rather than opting for faceting, Vollers decided to go for real curved
To curve the glass panes large moulds are milled from cellular concrete and placed in the furnace of glasbending firm Bruining in the city of Dordrecht. The furnace was fired at 700°C.

Two curved panes are turned into insulating glass, following a process very similar to that with flat panes. The Glaverbel Stopsol Supersilver Ice Blue glass panes have a highly reflective ceramic coating, which withstands high bending temperatures and emphasises the curving.

The 3D curved edges of the glass panes were cut along the sides of moulds milled from polystyrene. These moulds were subsequently used for transport from the glass manufacturer to the aluminium assembler.

The next step is the development of an adjustable mould. This one, designed by architect Lars Spuybroek. It is similar to the principle that is being studied by the BLOB group of the Building Technology department at Delft University.

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