Other geometries in architecture: bubbles, knots and minimal surfaces

Tobias Wallisser

Abstract. Geometry has always played a key role in the design and realization of architectural projects. In his book "The projective Cast", the English Architect and Theorist Robin Evans described how the production of architecture is linked to the representational techniques available. In the mid-nineties, the "first wave" of digital architecture hit the world and triggered a digital revolution of the profession. However, with this first wave, there was no gravity, nothing for the senses and very little constraints. Thus architecture divided between the digital visionaries and the 'real' architects who build. In today's second wave 'the digital' enables us to conceptualize and build in an entirely different fashion. The computer now enables that which divided us: to build. The understanding of Geometry plays a mayor role in the application of the new digital techniques by architects. Sometimes, it is used as an inspirational concept, but more and more often a deep understanding of geometrical relationships is the key for parametrical optimisation and associative modelling techniques. These design processes trigger a different notion of form as the result of a process rather than the idea of a single designer. Although the application of mathematical principles is crucial for the realization of many contemporary designs, the idea of taking inspiration from nature or abstract mathematical principles at the base of natural order is more fascinating. These principles, such as minimal surfaces, repetitive tiling or snowflake formations can be used as inspiration to develop abstract diagrams that in turn can be refined and enriched with architectural information to become prototypical organizational models for buildings. Illustrations of mathematical concepts like knots or visualizations of algorithms provide another source of inspiration. They open up the possibility to think about other worlds, environments and building concepts, besides the platonic solids, Cartesian grids and equally spaced grid systems that dominated architecture for so many centuries.

Emmer M, Quarteroni A (Eds.): MATHKNOW.

1 Introduction

In being asked to give a lecture about the use of mathematics in Architecture, many different attributes within this theme sprang to mind.

Geometry has always played a key role in the design and realization of architectural projects. In his book "The Projective Cast", the English Architect and Theorist Robin Evans described how the production of architecture is linked to the representational techniques available at that time [4]. Through the need to communicate ideas and formal aspects of the buildings designed, architects work on the representation of rather than the actual objects themselves. Architecture is always "acting at a distance" as Evans explained, due to a translation process that forms part of every step in the design process. An idea needs to be sketched out on paper, a concept has to be presented to the client in the form of a model or perspective visualization and building information including dimensions, materials and technical aspects has to be brought to the construction site. In every case, a two dimensional representation is needed. Whilst drawings are incredibly efficient and dense pieces of information, they might also limit our possibility to express and develop ideas.

Is there new potential to augment these proven techniques and to push the boundaries provided by computational techniques?

Architecture is, after all, a slow and costly process dominated by labor-intensive processes and great responsibilities. In the mid-nineties, the "first wave" of digital architecture hit the world and triggered a digital revolution within the profession. However, with this first wave, there was no attention given to gravity, not much for the senses and very few constraints. Thus architecture was divided into two sectors: the digital visionary designers and the 'real' architects who built.

In today's "second wave", digital working processes enable us to conceptualize and to build in an entirely different manner. We are currently facing times in which technological progress becomes a useful tool in overcoming the division it once generated. Architecture is undergoing an interesting process of transformation. Rather abruptly, we are experiencing the emergence of something which I would like to describe with a term from John Raichman, "Other Geometries": "*Other geometries* thus require other ways of knowing that don't fit the Euclidean model. They are given by intuition rather than deduction, by informal diagrams or maps that incorporate an element of free indetermination rather than ones that work with fixed overall structures into which one inserts everything" [3].

During the Renaissance, Alberti developed the concept of the separation between the structure and skin of buildings. This concept became the dominant idea of modernism in the 20th century and was taken up by Le Corbusier who developed the 'five points of architecture' as the key concepts for modern building design.[1] Buildings were planned and developed in successive steps –

[1] "Les 5 Points d' une architecture nouvelle", which Le Corbusier finally formulated in 1926 included (1) the pilotis elevating the mass off the ground, (2) the free plan, achieved

first the structural elements or "bones" were defined, then the cladding and façade as a separation between inside and outside was to follow. Digital technologies allow this separation to diminish and at once we can reconsider our buildings as coherent structures where structure, skin and ornament are inseparable. The spatial organization of Gothic cathedrals is a good example to illustrate this principle of integration.

The understanding of Geometry plays a mayor role in the application of new digital techniques by architects. Although geometrical principles are sometimes used as an inspirational concept, more and more frequently a deep understanding of geometrical relationships is becoming the key for parametrical optimization and associative modelling techniques. These design processes trigger a different notion of form – as the result of a process rather than the idea of a single designer.

Henceforth, I would like to focus on the aspect of mathematical models being a source of inspiration rather than being turned (literally) into large scale structures or being applied to calculate and optimize local problems related to manufacturing or building processes.

Although the application of mathematical principles is crucial for the realization of many contemporary designs, to me the idea of taking inspiration from nature or abstract mathematical principles at the base of natural order is even more fascinating. These principles, such as minimal surfaces, repetitive tiling or snowflake formations can be used as inspiration to develop abstract diagrams that in turn can be refined and enriched with architectural information to become prototypical organizational models for buildings. Illustrations of mathematical concepts like knots or visualizations of algorithms provide another source of inspiration. They open up the possibility to think about other worlds, environments and building concepts, besides the platonic solids, Cartesian grids and equally spaced grid systems that dominated architecture for so many centuries.

Working with inspiration found outside the discipline of Architecture itself requires rethinking the working methods. The architect and designer Greg Lynn speaks about "alternative mathematics" [3] that need to be applied in such circumstances. In the words of John Raichman, "an informal mathematics of the singular with its open-ended variability or iterability rather than a deductive mathematics of the general with its particular variants" is characteristic for these projects [3]. Rather than starting with known formulae and standard typologies or systems, the architect first needs to define the principle before it can be transported into an architectural design. Diagrams form an ideal basis for this process. They are an alternative to representational systems or linguistic models as they are non-signifying and non-representational descriptions of relationships, therefore not dependent

through the separation of the load-bearing columns from the walls subdividing the space, (3) the free facade, the corollary of the free plan in the vertical plane, (4) the long horizontal sliding window and finally (5) the roof garden, restoring, supposedly, the area of ground covered by the house.

on cultural preconception. Christopher Alexander, who holds a Bachelor's degree in Architecture and a Master's degree in Mathematics, developed a technique using diagrams to structure the design process. He distinguishes between form diagrams, requirement diagrams and operational diagrams. His systematic approach influenced other disciplines more than architecture, but it still has an impact on contemporary practices. Applying diagrammatic techniques allows the essence of a system to be captured, rather than its form. In architecture, this enables the collection of constraints and limitations as starting points for formal, spatial or organizational investigations. "What would it mean thus to put into practice an experimental art of singularizing space through informal diagrams geared to sometimes even quite small "virtual futures", which deviate from things known . . ." [2].

Four recent projects with which I would like to illustrate the results of contemporary digital design processes in combination with the inspiration of mathematical models are that of: The Water Cube; The Mercedes Benz Museum; The Michael Schumacher World Champion Tower; and The Green Void Installation.

The former two of these abovementioned building structures have been completed and are regarded as highly exemplary in the use of rule-based design models that articulate complexity, whilst resulting in elegant and innovative spatial structures. The remaining two projects are examples of a continuous journey of the application of mathematically inspired principles in our LAVA architectural practice.

The Water Cube project for the Olympic Swimming Venue in Beijing is considered an architectural milestone in the field of computational design and construction and was highly anticipated as one of the most important buildings of the 21st century.

Fig. 1. These four projects will be useds as references (from left to right): the Water Cube in Bejing, the Stuttgart Mercedes-Benz Museum, the MSWCT tower in Abu Dhabi and the green void installation in Sydney

The Stuttgart Mercedes-Benz Museum is not based on elevations and plans, but three-dimensional spatial experiences. It was conceived 3-dimensionally, through movement and not in elevation, plan or section. Its construction was only possible by introducing a rigorous geometrical system that enabled coherent design decisions and control of the technical execution simultaneously.

The Michael Schumacher World Champion Tower project was inspired by the geometrical order of snowflakes and the aerodynamics of a Formula 1 racing car. It encapsulates speed, fluid dynamics, future technology and natural patterns of organization.

The green void installation in Sydney embodies an installation shape that is not explicitly designed, but rather is the result of the most efficient connection of different boundaries in three-dimensional space (these can be found in nature in examples such as plant life and coral).

2 Water Cube, PTW Architects, ARUP, CSCEC, 2008

The so-called Water Cube associates water as being a structural and thematical "leitmotiv" with the square, the primal shape of the house in Chinese tradition and mythology. In combination with the main stadium by Herzog & de Meuron, a duality between fire and water, male and female, Yin and Yang is being created with all its associated tensions/attractions.

Conceptually the square box and the interior spaces are carved out of an undefined cluster of foam bubbles, symbolizing a condition of nature that is transformed into a condition of culture. The appearance of the aquatic center is therefore a "cube of water molecules" – the Water Cube. Its entire structure is based on a unique lightweight-construction, developed by PTW with ARUP, and derived from the structure of water in its aggregated state (foam). Behind a seemingly random appearance hides a strict geometry, as can be found in natural systems such as crystals, cells and molecular structures – the most efficient subdivision of 3-dimensional space with equally sized cells.

The development of this structure dates back to 1887, when Lord Kelvin asked how space could be partitioned into cells of equal volume with the least possible area of surface between them, i.e., what was the most efficient soap bubble foam? This problem has since been referred to as the Kelvin problem. He found the so-called Kelvin conjecture, in which the foam of the bi-truncated cubic honeycomb was considered the most efficient structure for more than 100 years, until it was disproved by the discovery of the Weaire-Phelan structure.

In 1993, Denis Weaire and Robert Phelan, two physicists based at Trinity College, Dublin, found that in computer simulations of foam, a complex 3-dimensional structure that was a better solution to the "Kelvin problem". The Weaire-Phelan structure uses two kinds of cells of equal volume; an

Fig. 2. The steel structure displays the 3-dimensional nature of the molecular structure of the Water Cube derived from foam bubbles

irregular pentagonal dodecahedron and a tetrakaidecahedron with 2 hexagons and 12 pentagons, again with slightly curved faces.[2]

Parallel to the work on the Water Cube, students were asked to study and research current trends in parametric modelling, digital fabrication and material-science and apply this knowledge to a space-filling installation.The aim was to test the rapport of a particular module, copied from nature, to generate architectural space – with the assumption that the intelligence of the smallest unit dictates the intelligence of the overall system. Ecosystems such as reefs act as a metaphor for an architecture where the individual components interact in symbiosis to create an environment. In urban terms, the smallest homes, the spaces they create, the energy they use, the heat and moisture they absorb, multiply into a bigger organizational system, whose sustainability depends on their intelligence. Out of 3500 recycled cardboard molecules of only two different shapes, the students created a mind-blowing reinterpretation of the traditional concept of space, which was exhibited at Erskine gallery in Sydney as the "Digital Origami" project [4].

The Water Cube's structural grid is rotated against the coordinates of the box volume, disguising the repetitive nature of the elements and in turn making them appear unique. By applying a novel material and technology, the transparency and the supposed randomness is transposed into the inner and outer skins of ETFE cushions. Unlike traditional stadium structures with

[2] Excerpt from Wikipedia

Note: It has not been proved that the Weaire-Phelan structure is optimal, but it is generally believed to be likely: the Kelvin problem is still open, but the Weaire-Phelan structure is conjectured to be the solution. The honeycomb associated to the Weaire-Phelan structure (obtained by flattening the faces and straightening the edges) is also referred to loosely as the Weaire-Phelan structure, and it was known well before the Weaire-Phelan structure was discovered, but the application to the Kelvin problem was overlooked.

Fig. 3. The inside of the Water Cube bar and the "digital origami" installation use the same principle of linear repetition at different scales

gigantic columns and beams, cables and back spans, to which a facade system is applied, in the Water Cube design the architectural space, structure and facade are one and the same element. As the counterpart to the Olympic Stadium (birds nest), the Water Cube became one of the most important icons of the Olympic Games 2008. It has been published worldwide and is recognized as one of the founding projects of the digital era.

Fig. 4. The outer skin of the building is made of ETFE membrane cushions

3 Mercedes-Benz Museum Stuttgart, UNStudio, 2006

The Mercedes-Benz Museum is one of the largest company-owned museums in the world. It displays the unique collection of the Mercedes-Benz brand, consisting of one version of almost every car the company produced since the invention of the car in 1886. At present, it attracts around one million visitors a year. The design was chosen as the winning competition entrant, the competition of which was held in 2001. UNStudio's successful competition entry was based on the project brief, the functional requirements and local factors, but also contained investigations into mathematical models that were partially done on other projects.[3]

In 1997, UNStudio completed the so-called Möbius house, a private villa inspired by the qualities of a Möbius strip. Since 1996, the office has worked on a large infrastructural project in Arnhem, where the concept of "knotted" surfaces, based on Seifert's interpretation of knots was applied to a landscape organization, then later in the main structural pivot. In UNStudio's description of the project, the Arnhem Central project is described as "a large urban plan development composed of diverse elements which amassed constitute a vibrant transport hub. Housed under a continuous roof element these programs constitute one of the main thresholds into Arnhem, its architecture adding to the iconography of the city." [5] This was achieved by organizing the floor as a landscape, with the entrances to the underground car and bicycle-parking garages organized by bifurcation of the main surface and a main structural element, the so-called "twist". This twist was derived from a spatial interpretation of a figure eight knot. Together with the structural engineer Cecil Balmond[4] and his team at ARUP in London, we developed a minimal surface that optimizes the span of the roof, organizes pedestrian flow on various levels in and out of the terminal building and provides orientation for the passengers. Consequently, this element became an icon for the entire development. This surface, interestingly, became too complex to be achieved with the methods employed by Frei Otto[5] but follows the same logic as his soap bubble experiments simulated in a virtual environment.

When the competition for the Mercedes-Benz Museum was started, 'knot' investigation was taken yet further. While the amorphous, fully double-curved concrete structure of the Arnhem station felt to be too complicated for a multi-storey building, the idea of a twisting surface creating connections between different floor plates was embraced. Located on a six-meter high platform of 285.000 m^2, the museum comprises 35.000 m^2 of exhibition space.

[3] UNStudio was founded in 1998 by Dutch architect Ben van Berkel and his partner Caroline Bos. The design and the construction process of the museum are documented in Andreas K. Vetter, UNStudio, and Mercedes-Benz Museum. Design Evolution.

[4] Cecil Balmond is Deputy Chairman of Ove Arup and Partners Limited, and Arup Fellow and Director of the Advanced Geometry Unit (AGU), which he founded in 2000.

[5] Frei Paul Otto (31 May 1925) is a German architect and structural engineer. Otto is the world's leading authority on lightweight tensile and membrane structures, and has pioneered advances in structural mathematics and civil engineering.

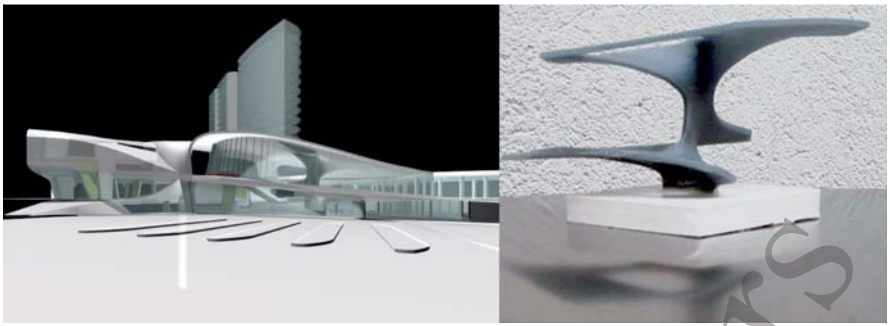

Fig. 5. Visualization of the Arnhem Interchange project at conceptual design stage and the so-called twist column as its most important structural element

Contrary to the trend of designing glass cubes for museums, the building is organized as a double helix made of concrete, glass and aluminium. The brief called for two distinct ways of walking through the collection. A chronologically structured path leading along all the highlights of the museum, displayed in "legend" rooms – and a secondary path, connecting rooms given over to thematically arranged "collection" spaces. For site-specific reasons, the museum was organized as a compact, vertical volume next to the highway bordering the site. The two pathways were intertwined in a double helix structure, an organizational principle well known from infrastructural buildings such as car parks. In opposition to Frank Lloyd Wright's famous concrete spiral of the Guggenheim museum[6], the spiralling paths do not wind their

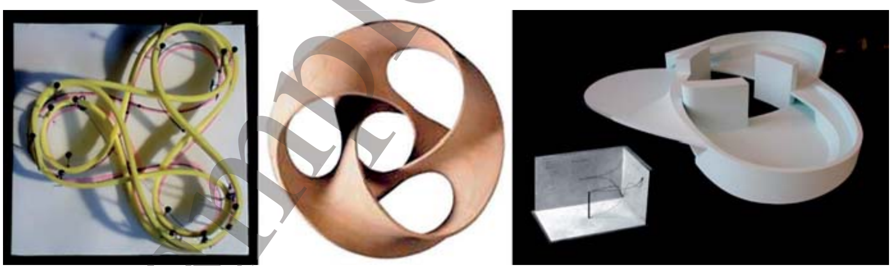

Fig. 6. Working models of the Mercedes-Benz museum: an interpretation of the trefoil knot as line and as knoted surface next to the final configuration of the floor plates. Two curved lines in space define the connection between two adjacent collection spaces

6 Guggenheim Museum New York, 1956–59, architect Frank Lloyd Wright, "Wright's great swansong, the Solomon R. Guggenheim Museum of New York, is a gift of pure architecture – or rather of sculpture. It is a continuous spatial helix, a circular ramp that expands as it coils vertiginously around an unobstructed well of space capped by a flat-ribbed glass dome. A seamless construct, the building evoked for Wright 'the quiet unbroken wave" [6].

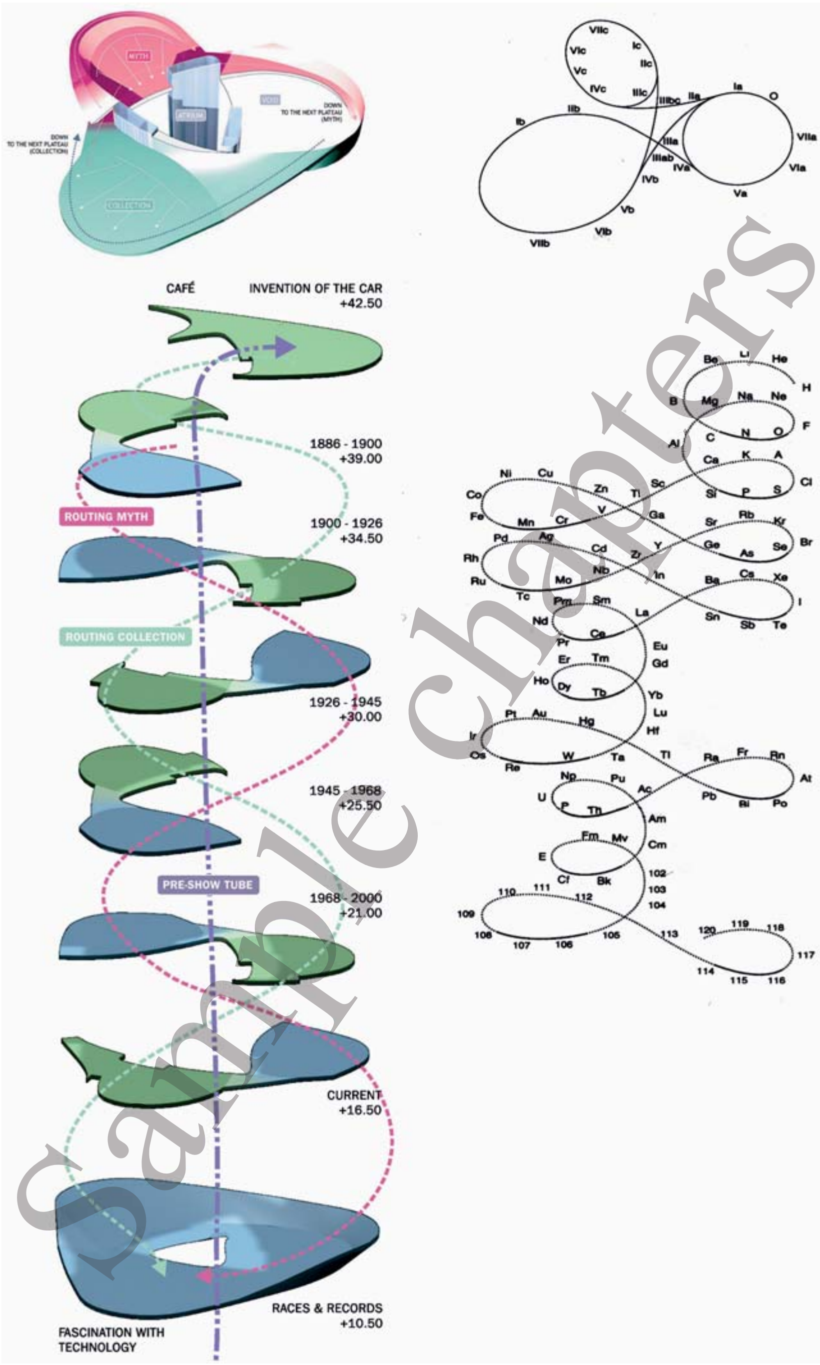

Fig. 7. The museum's organizational principle is based on a double helix principle wherby identical floor plates are rotated by 120 degrees every floor

way up in a continuous manner. In plan, the arrangement is based on an equilateral triangle, oriented towards the three highways, which meet at the site.

All rooms are arranged as horizontal plateaus connected by ramps and staircases. Since the legend rooms are twice as high as the collection rooms, a compact stacking of plateaus, consisting of an integration of both a legend and a collection space was made possible by rotating every plateau 120 degrees on every floor. The structural principle was inspired by a version of a trefoil knot which was interpreted as an intertwined continuous surface. Due to the necessity of connecting five floors, this principle was only applied locally and became a propeller-like element connecting two adjacent collection spaces. This element is formed by two spatially curved lines and is inspired by images of old plaster models of mathematical equations, discovered in a publication [7]. Following the lines of the trefoil projected onto a spiral, the

Fig. 8. Section and main elevation of the Mercedes-Benz museum showing the differntiation of closed legend space facades and the panorama window accompanying the collection helix

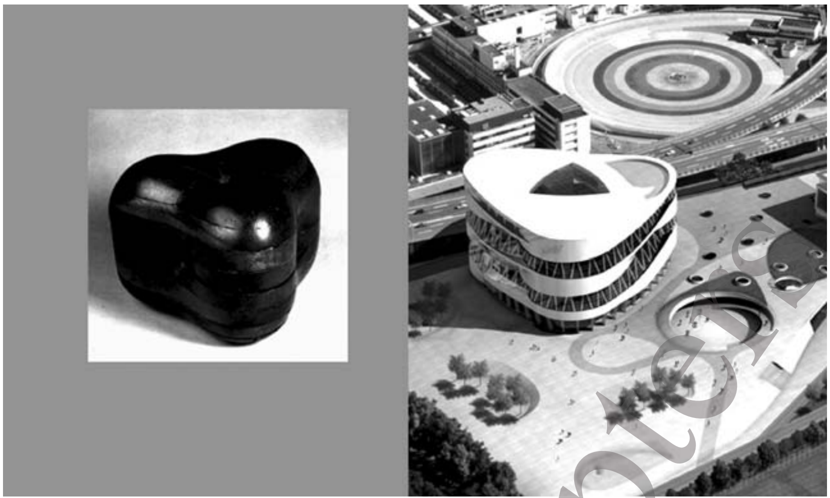

Fig. 9. An aerial view of the building compared to a mathematical model reveils similar massing and features

edges of all surfaces are built from in situ concrete, whereas the floor plates are filled in with a lighter steel structure for the plateaus. Due to the rotation and the intrinsic puzzle of stacked legend spaces which are oriented towards the atrium and closed to the outside and collection spaces, hidden from the atrium by the propeller elements and largely glazed to the outside, the section of the building allows the reading of a folding surface stretching from the ground to the top of the building.

The outer façade does not reveal the complex internal organization immediately. The double helix organization is partly reflected in a closed and an open glazed spiral, yet these elements are intertwined in the areas above the propeller-like elements connecting the collection rooms. At these points, the angled glass façade moves to the inside, the upper line following the trefoil lines of the legend spiral whilst the lower remains on the convex outer edge of the collection spiral. At these points, sharp edges appear in the smooth outer form of the massive building, a feature inspired by the continuous curvature from outside to inside found in the model of a quartic [8].

In order to control the complex spatial arrangement and the construction sequence, the entire building was organized by a rigid parametrical model based on arcs. The so-called "problem of Apollonius" was the solution to many geometrical issues, connecting two arcs with another tangential arc. In an iterative process of more than 50 geometrical definitions, the main frame of the structure was geometrically defined before freezing the geometry and only allowing local adjustments to occur. By keeping all arcs in horizontals planes and creating ramps through the projection of Z-coordinates the building could still be represented in drawn format.

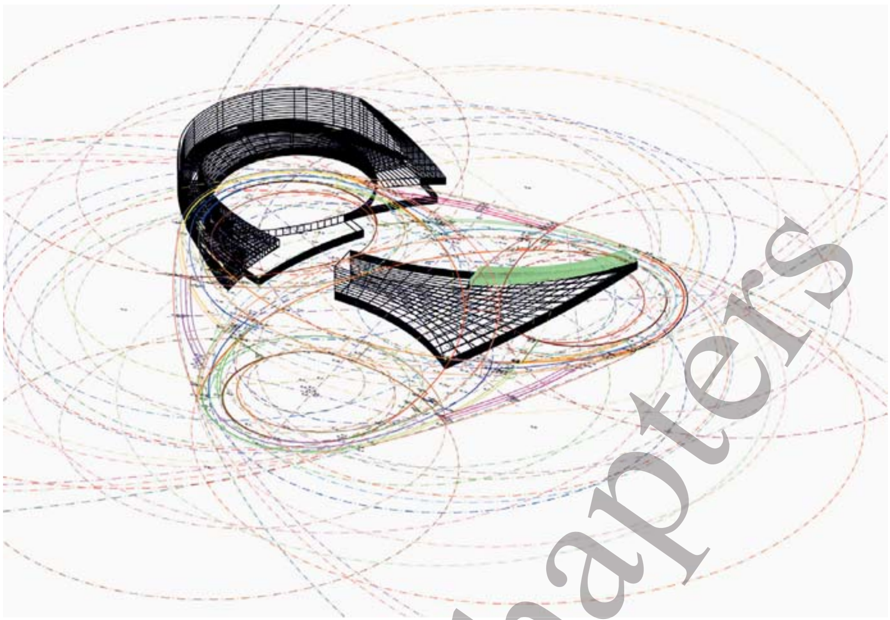

Fig. 10. The geometrical build-up of the double-curved elements. All curves are placed in a horizontal plane from where the z-coordinates were projected

Fig. 11. Photo of the construction site. The trefoil principle is translated into concrete elements framing the horizontal floor plates

Fig. 12. A view from one legend room through the atrium into the next plateau. The core wall on the right side transforms into the diagonal connection between two collection spaces

The building became well known as a new type of technical museum, capturing movement in built form. It also became renowned as a prime example of a digitally imagined and designed piece of architecture. The interior spatial organization creates a rememberable experience. The building twists and turns away from the spectator while opening up new views to the outside and adjacent spaces inside in an almost kaleidoscopic manner. A spatial composition reminiscent of baroque spaces, the Mercedes-Benz Museum was described as the first building of a new architecture termed "Digital Baroque" [9].

4 The Michael Schumacher World Champion Tower Abu Dhabi, LAVA, and Wenzel+Wenzel, 2008

This project develops on our previous experience – the work on the rotational symmetrical Mercedes-Benz Museum with the modular organization of the Water Cube in Beijing. Having being asked to design a building that would represent the achievements of a legendary formula one race driver, we looked into creating a highly emotional but rationally describable tower geometry.

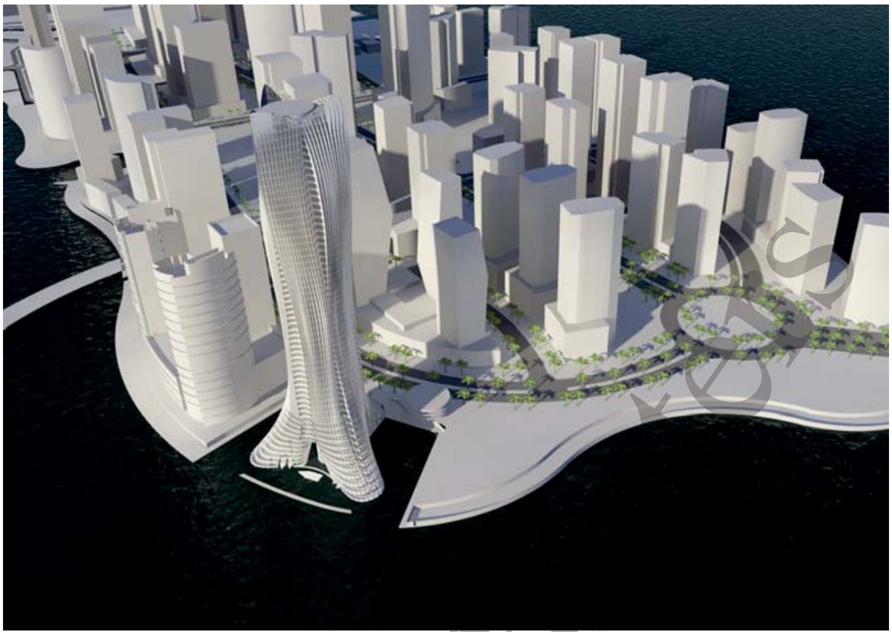

Fig. 13. The MSWCT tower is situated on the tip of Reem island and will be surrounded by water

Inspired by the geometrical order of a snowflake[7] and the aerodynamics of a Formula 1 racing car[8], the tower encapsulates speed, fluid dynamics, future technology and natural patterns of organization. Rather than purely mimicking shapes in nature for their elegance and unpredictability, the design was influenced by nature's own geometrical orders creating highly efficient structures and intriguing spaces.

The design unfolded as a result of the project's needs: optimal natural light and air distribution, maximum views, minimal structure, user comfort and an unrivalled water experience. The organizational principle of a minimal surface[9] allowed the optimization of the facade/floor area ratio and each apartment in the 59-storey luxury tower has unobstructed ocean views.

The lower levels of the tower, traditionally the most difficult and least attractive area, has been reinterpreted as a series of prestigious wharf apart-

[7] Snow flakes by Wilson Bentley; Plate XIX of "Studies among the Snow Crystals ..." by Wilson Bentley, "The Snowflake Man." From Annual Summary of the "Monthly Weather Review" for 1902. Bentley was a bachelor farmer whose hobby was photographing snow flakes. Image from Wikipedia.

[8] During wind tunnel testing, the aerodynamics of the car's body are made visible and create patterns of lines moving across the surface.

[9] Digital model similar to this sculpture at the Stuttgart Academy built by my college Stephan Engelsmann and students in 2007.

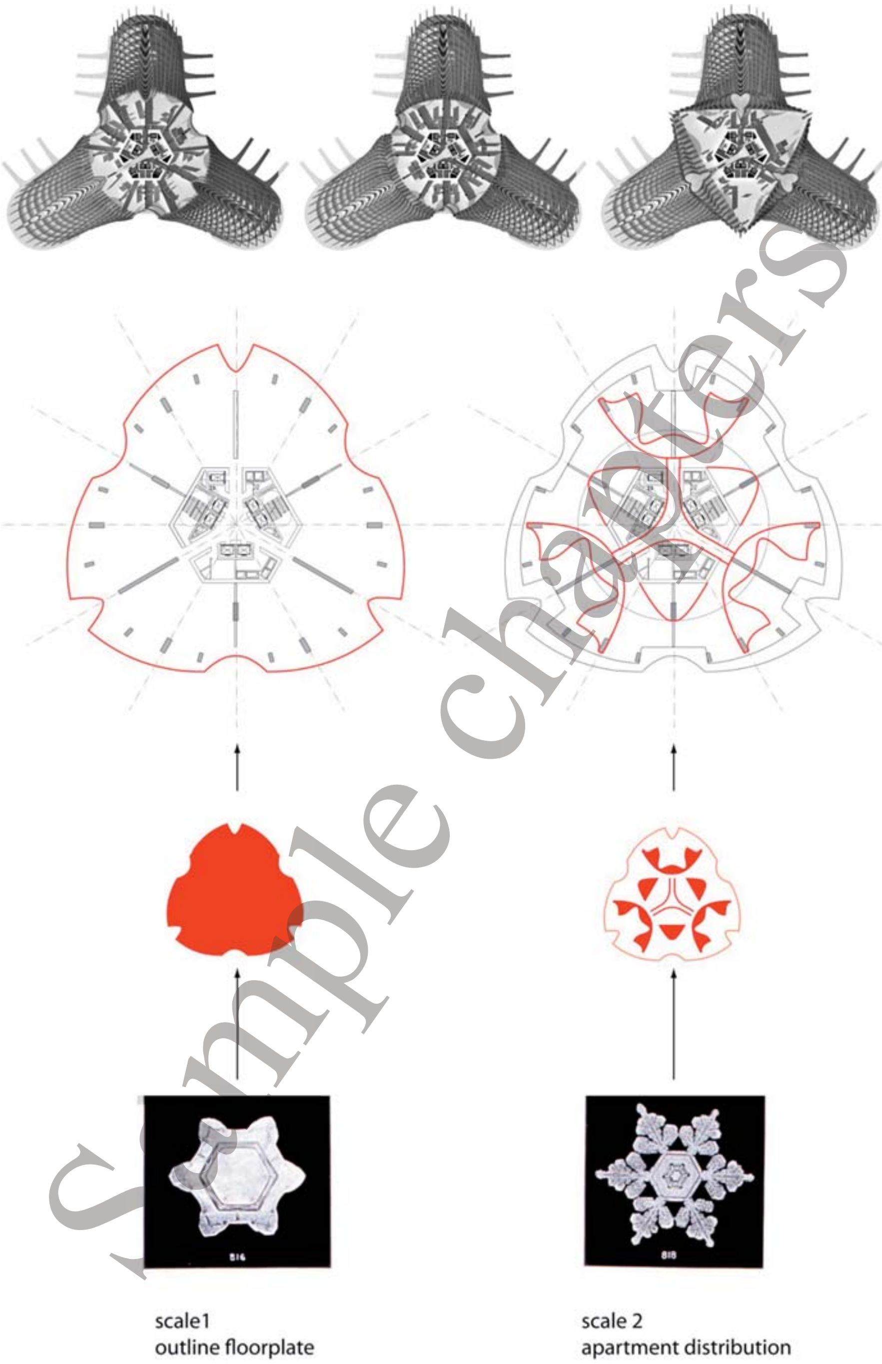

Fig. 14. Different floor plates of the tower. The shape and the interior organization are inspired by snowflake patterns

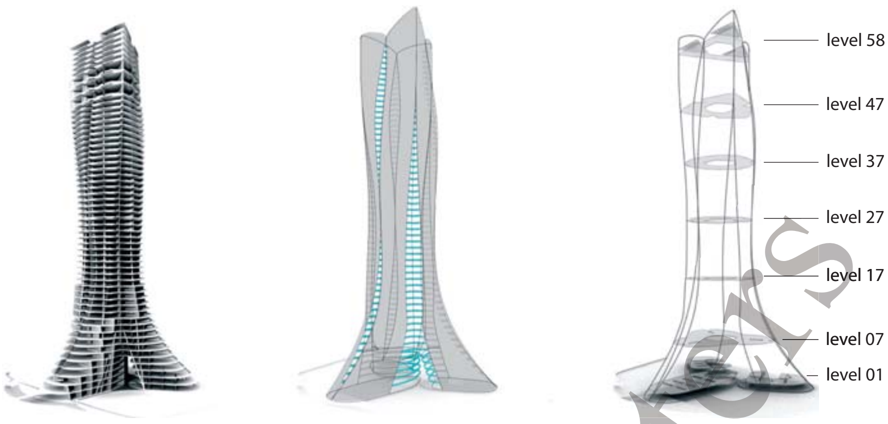

Fig. 15. The key elements of the tower design: the floor slabs, the balcony slots and the facade fins

ments, terraced similar to that of cruise ship decks. By widening the base, the tower is anchored to its surrounding water basin – similar to the surrounding mangroves and nearby canals.

The spacious decks of the lower wharf apartments are taken up into the structure as balconies, occupying slots in the facade within the hollows of the original minimal surface object. The snowflake geometry was interpreted as shapes with a fractal nature of edges. Depending on the quantity of apartments on every floor, the perimeter is adjusted, allowing for a differentiation of apartment types and sizes.

The Sky Villas offer 240-degree views through to the new cultural district on Saadyiat Island opposite. The building features an iconic silhouette and a facade characterized by vertical slots with private balconies. A series of reflective fins generates a vertical dynamic and gives the building a constantly changing appearance. The fins track the sun, control the solar shading and dissolve the rationality of the plan into a continuously evolving building volume.

The façade's continuous surface, in combination with the symmetrical plan, enables curvature within repetition and the potential for standardization in the building process. State-of-the-art engineering and innovative materials will be used to achieve a fully sustainable structure. Ground breaking is expected in 2009.

5 Green void installation in Customs House, Sydney, LAVA, 2008

When LAVA was asked to design this year's installation for the atrium space in Customs House at Sydney's Circular Quay, we considered an efficient way of achieving more with less. The starting point was research into 'minimal surface' forms, the most efficient structures known in nature. The 'minimal surface' of the installation consists of a tensioned stretch fabric, digitally patterned and custom-made for the space. The five "funnels" of the sculpture reach out to connect the various levels of the building. These precariously hover just off of the main interior atrium of Customs House, above the model of the city.

The shape of the installation object is not explicitly designed; it is rather the result of the most efficient connection of different boundaries in 3-dimensional space, (to be found in nature such as plant life and coral). Whilst we determined the connection points within the space, the following result is a mathematical formula, a minimal surface. Although appearing solid, the structure is soft and flexible and creates highly unusual spaces within the Customs House building, which also are emphasized with projection and lighting. Since the 1970's, with Frei Otto's soap-bubble experiments for the Munich Olympic Stadium, naturally evolving systems have been an intriguing area of design research.[10] Our team shares his fascination with new building ty-

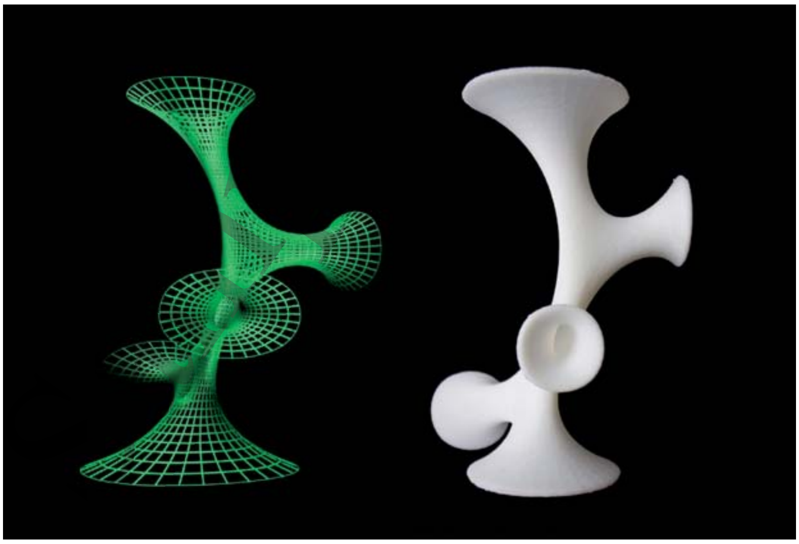

Fig. 16. A digital model and a rapid prototype of the minimal surface used for the installation

[10] Soap bubble experiment, ILEK Universität Stuttgart, Frei Otto 1970, see also footnote 5.

Fig. 17. The fabric installed transformed the void of customs house

pologies and naturally developed structures. We sought for advice and inspiration from American artist Alexandra Kasuba, who since Woodstock 1972 has created imaginative membrane sculptures around the world, followed by international artists such as Anish Kapoor and Ernesto Neto.[11]

[11] Ernesto Saboia de Albuquerque Neto (Rio de Janeiro, Brasil 1964–) is a contemporary visual artist. Anish Kapoor (born in India 1954) is one of the most influential sculptors of his generation. Kapoor's pieces are frequently simple, curved forms, usually monochromatic and brightly colored.

Fig. 18. A view into one of the trumpet-shaped ends of the sculpture

The realization of the concept was achieved with a flexible material, which follows the forces of gravity, tension and growth – similar to that of a spider's web or a coral reef. The lightweight fabric design follows the natural lines, contours and surface-tension. No drawing was necessary, the patterns of the fabric were cut digitally using the unfolded surfaces from the 3d-model. With a surface area of only 300 m^2 and merely 40 kg in weight the object occupies 3000 m^3. Rising up to the top level restaurant, a vertical distance of almost 20 m, the sculpture provides an intense visual contrast to the beautifully restored heritage interior of Customs House.

Designed as a piece of art, the sculpture is at the crossing point of art, architecture and technology brought together by the potential of contemporary computational calculation and manufacturing methods.

These diverse examples show that the process of designing an architectural project in a scientific manner is unnecessary. Vitruvius' statement that architecture is the mother of all arts may still be arguable, but architecture could well be seen as a sister of the arts, engaged in a constant dialogue. Simultaneously, architects have to deal with their client's needs, economic demands and technical possibilities. Within certain parts of the design process, complex networks of dependencies need to be managed. This is most likely the reason why the appropriate use of mathematical formulae or pure form deriving from it, rarely is successful in architecture. Mathematical concepts, however, which are beyond geometry, can be a rich source of inspiration for architects and result in building structures that would have otherwise been unimaginable.

As the architect Louis Khan said: "A great building must begin with the unmeasurable, must go through measurable means when it is being designed and in the end must be unmeasurable."[12] This can be applied to the role mathematical concepts can play in architecture: they can provide inspirational models of thought at a conceptual level, they are vital as rule-generators and tools for parametric optimization throughout the realization of a project. What we should be aiming for, though, are the effects of the built work to surpass calculation.

References

1. Evans, R.: The Projective Cast: Architecture and its Three Geometries. MIT Press (2000)
2. Rajchman, J.: Constructions. MIT Press (1998)
3. Ibid, chap. 6: Other Geometries
4. Digital Origami, Erskine gallery space Sydney, exhibition of UTS students, instructor Chris Bosse (2007)
5. UNStudio project description of Arnhem Central (2005)
6. Kostof, S.: A History of Architecture, Settings and Rituals, p. 740. Oxford University Press, New York (1985)
7. Fischer, G.: Mathematical Models, illustration of space curves, p. 59. Vieweg (1986)
8. Ibid, Quartic, p. 52/53
9. Rauterberg, H.: DIE ZEIT, November 3 (2005)

[12] Louis Isadore Kahn (born Itze-Leib Schmuilowsky) (February 20, 1901 or 1902 – March 17, 1974) was a world-renowned architect of Estonian origin based in Philadelphia, United States.

http://www.springer.com/978-88-470-1121-2

MATHKNOW
Mathematics, Applied Science and Real Life
Quarteroni, A. (Ed.)
2009, XI, 264 p., Hardcover
ISBN: 978-88-470-1121-2