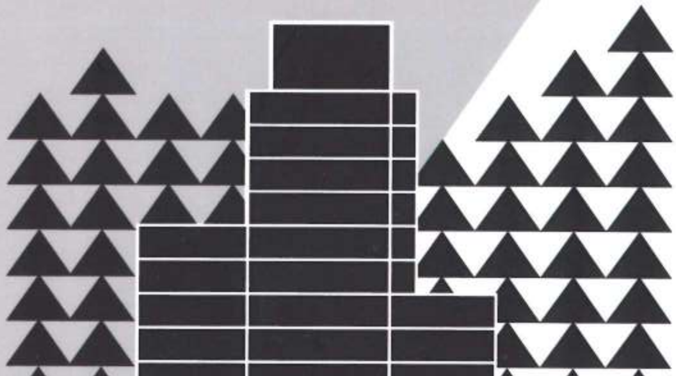
NEXUS 2021

Architecture and Mathematics

Conference Book



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Nexus 20/21
Architecture and Mathematics

Conference Book

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Contents

CONFIGURATION VS. STRUCTURE: FORM FOLLOWS FUNCTIONS

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Introduction

This contribution is inspired by a quote of the engineer Tony Guéritte (1932): "*The hyperboloid of revolution, in its simplicity as a mathematical body of pure lines, gives a feeling of strength, stability and industrial beauty*". It is reiterated that a surface makes clear an architecture, being its skin, the exterior part, thus giving it a formal connotation. The research therefore aims to analyse a hyperbolic hyperboloid, a cooling tower in Marghera now dismissed and converted.

The research intends to clarify first the occurred analytical-geometric-historical process of the tower and its construction, then to demonstrate the geometric-mathematical importance of the hyperboloid of revolution to maximize the structural and thermodynamic performance of the tower. Through the simultaneous interface between parametric models and physical simulation environments, the study shows how the tower of the case study represents one of the possible optimization values in the domain of realizable hyperboloid forms.

The Research

This research highlights the role that surfaces and the related geometric-mathematical knowledge has for architecture not only in formal terms, but also in structural terms. It tries to overcome a reductive use of the surface concept, connecting it to adjectives as 'superficial', 'external' and, in the worst cases, as 'trivial'. In 1999, in the book '*Cupole, volte e altre superfici*', it was reported: "*In architecture this surface (hyperboloid) was adopted in a specific period, when the as called tense structures were discovered. Also Le Corbusier uses it in Chandigar, Kisho Kurokawa in Abu Dabi and, more unimportantly, it is applied to the external structure of thermal power plants*". Twenty years later this claim appears inadequate. In fact, after the research on the case study of the cooling tower in Marghera, it was also overturned the contrast between the concept of "engineering structure" and "architectural design".

Apart from this remark – or perhaps because of it – a deep study of the concept of surface related to any engineering and architectural work seems necessary. For this reason, for each of them a rigorous geometric analysis is fundamental, it expects to identify its own configurative genesis. In fact the genesis knowledge of each surface

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allows a first definition according to the mathematical common characteristics to other surfaces of the same family. Only by referring to the canonical classification of surfaces, it is emphasised how complex can be the 'superficial' study of an architectural artefact. Just considering the same surface generated in different ways - changing the generator element and the law of movement- makes it essential to have a critical "attitude", not only in the representation phase, but also in the one of project, planning, construction and maintenance.

Subsequently a correct awareness of the geometric figures makes it possible to easily cross the border of that dense network between ideas and reality, becoming outstanding 'messengers' inside that network. Marsilio Ficino, in one of his numerous demonstrations on the incorporeal nature of beauty (involving colour, light and numbers as formal and order principles) required his reader to visualize a building, and then to try to neutralize in their mind its material nature, leaving visible only the internal geometric order:

Sforzati un poco a trarne la materia, se tu puoi: tu la puoi trarre col pensiero. Orsù trai a lo edificio la materia e lascia sospeso lo ordine: non ti resterà il corpo materiale.	*Struggle a little to draw the substance, if you can: you can draw it with thought. Now bring the substance of the building and leave the order suspended: you won't have the material body.*

Following Ficino's "instructions", we can un-materialize the form. But it is essential to reverse this process, so that these forms can be made by a material precision to satisfy our imagination, freed from the pure ideal location. This is the primary purpose of the link between architectural concept and geometric / mathematical genesis. This relationship must promote and stimulate the originality of the designer, who in an initial state in which the idea is born, thinks and generates the architectural work – *in fieri* – in configurative terms of the spaces. Above all it makes those works realizable, considering their structural and constructive features: the semantic value of a surface therefore becomes fundamental for its structure. As Guéritte states, this is the case of the hyperbolic hyperboloids.

Trying to consider the generative variety of a hyperbolic hyperboloid (or one-sheeted), it is:

1. a ruled surface generated by a straight line, which moves in space, constantly leaning on three lines, skewed two by two.

2. a surface generated by an ellipse (or a circumference) of variable size, which moves by leaning on two points of a fixed hyperbola, the plane always keeps the same position, and running its centre-point on a line overlapping with the diameter of the hyperbola, conjugated to the direction of the strings, corresponding to the support points of the ellipse (or of the circumference);

3. a surface of rotation, generated by the rotation of a branch of hyperbola around one of its non-transverse axis (hyperbolic hyperboloid of rotation) or of a straight line

around an axis, not coplanar with it, related to an axis of rotation (getting, again, a ruled surface).

It is therefore easy to understand that the actual feasibility of a hyperbolic hyperboloid cannot ignore the multiple and complex geometric genesis.

The study proposed, implementing an innovative research methodology by a multidisciplinary work group, highlights the described strong bond through the study of the natural cooling tower in Marghera. The applied method in fact is based on the cohabitation and the relation of a historical archive / document research, of a high precision digital survey and of a digital model.

All of this has allowed not only to understand the evolution of the building - from the construction to the actual state, up to a subsequent restoration works - but also to implement the interactions between advanced analytical methods, including the geometric / mathematical, structural and fluid dynamics. The investigation, elaborated in several phases, had in fact the focus on the link between every disciplinary characteristic with the formal development of the tower, identifying the connection between the geometry and the performances that the cooling tower had to satisfy during the operation phase.

From the analysis of the historical beginning of the cooling towers, it was possible to repeat the fundamental and following steps that allow to identify, in the hyperbolic reinforced concrete hyperboloid, the perfect balance between geometry and performance. There were two significant elements in the experimentation process on cooling towers: the shape and the material. The first examples were made of wood on rectangular plants, characterized by a limited duration and a poor circulation of water volumes. Then there are the metallic cylindrical towers, based on frame structures, with even worse results. From the earliest years of the twentieth century, however, the engineers successfully tested the use of cylindrical reinforced concrete cooling towers, a construction technique patented by the French François Hennebique in 1982. The use of this material and the circular base section had multiple advantages from multiple points of view. Reinforced concrete had the advantage of being resistant to both the action of water steam and fire, it did not require maintenance and offered perspectives that persisted much longer than wood and metal. Moreover, the cylindrical towers guaranteed a better distribution of water inside them and an excellent resistance to the action of the wind. Once the suitable material and the optimal planimetric plant, reinforced concrete and the circular one respectively, were found, the engineers began to work on the volumetric development of the cooling towers looking for the maximum efficiency. Problems were soon highlighted also for the cylindrical towers, especially when they reached large diameters, more and more required by industrial plants.

The director of the Dutch State Mines, Frederik van Iterson, with the help of Gerard Kuypers developed, a cooling tower based on completely new principles, that transform this type of plant: the hyperbolic tower. Starting from the invention of the Dutch engineer, a flourishing debate was soon run and an intense construction activity of hyperbolic towers of different sizes and different profiles took place.

Around the section of the *Société des Ingénieurs Civils de France* gathered the most innovative engineers in the field, including the same Van Iterson and Guéritte.

The hyperbolic refrigerant of Vetrocoke in Porto Marghera also was born from this pioneering environment in the field of applications of reinforced concrete in the industrial field. Built between 1937 and 1938, it comes from a French model belonging to the *Réfrigérants hyperboliques* of Paris, as indicated on the project tables.

Conclusion

It was therefore possible to understand, through historical research, survey and digital modelling, the authentic structural realization of the tower, highlighting its close link with the geometric / mathematical genesis. But, as stated, the double-curved shape not only guarantees surprising structural behaviour, but also optimizes its function of cooling water and expelling steam. In fact, through computational fluid dynamics algorithms the model of the envelope surface has shown the increase in velocity and temperature inside the hyperboloid form, compared to the primitive form, the cylindrical one. The double curvature of a hyperbolic tower therefore, on one hand it gives a remarkable structural strength and further improves the aerodynamics compared to the cylinder, allowing a uniform weight discharge on the ground. On the other hand it increases the draft of the air and evenly distributes the water reaching its full cooling function.

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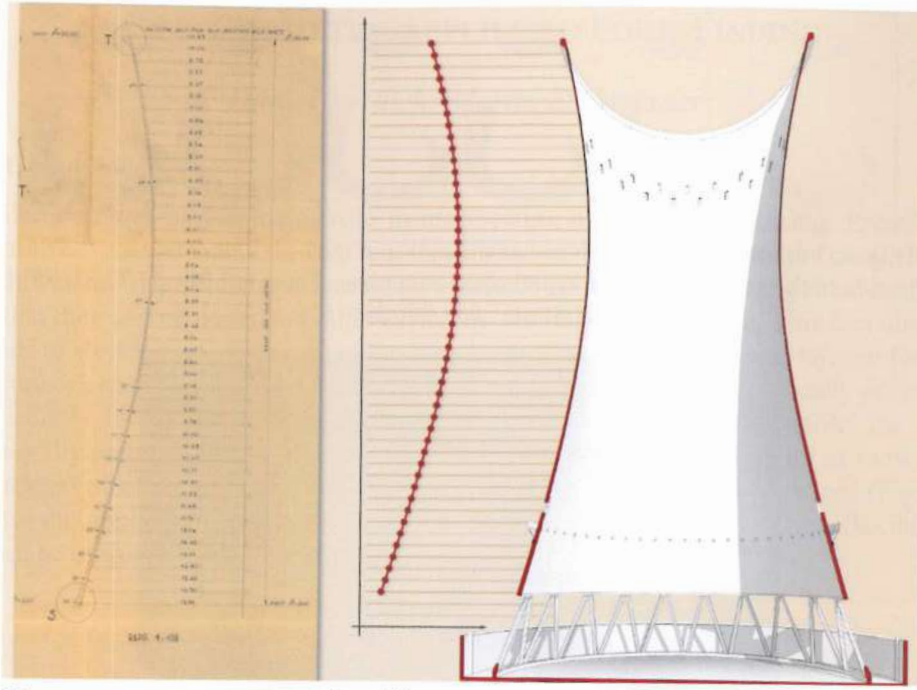

Fig. 1. Hyperbole equation and graphic. Project information and as built. Comparison

Fig. 2. Point cloud of the hyperboloid hyperbolic as built

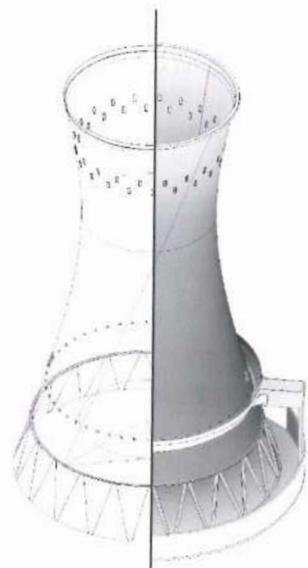

Fig. 3. Geometric schema of the hyperboloid hyperbolic and the obtained BIM model

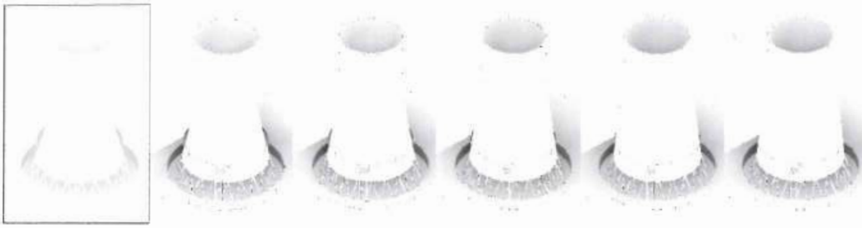

Fig. 4. Variation of the angle between the radius of the base circumference and the projection of the generatrix on the hyperboloid base plane. From left β1= 91,7° β2=75° β3= 60° β4=45° β5= 30° β6=15°

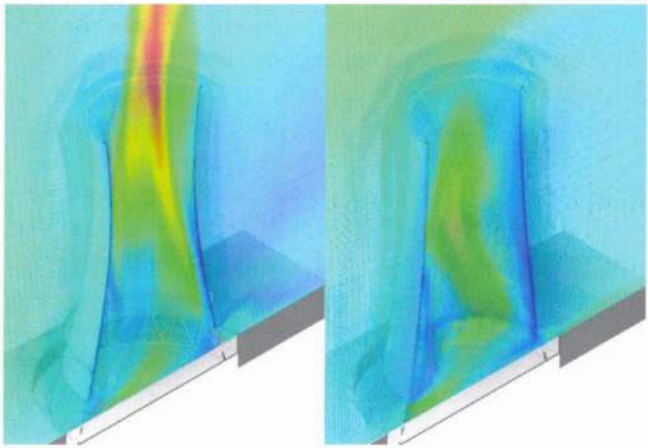

Fig. 5. CFD simulation of the air flow velocity of the air (m/s). Analysis made through the variation of the angle between the radius of the base circumference and the projection of the generatrix on the hyperboloid base plane. The two represented towers have an angle of β1= 91,7° β2=15° respectively

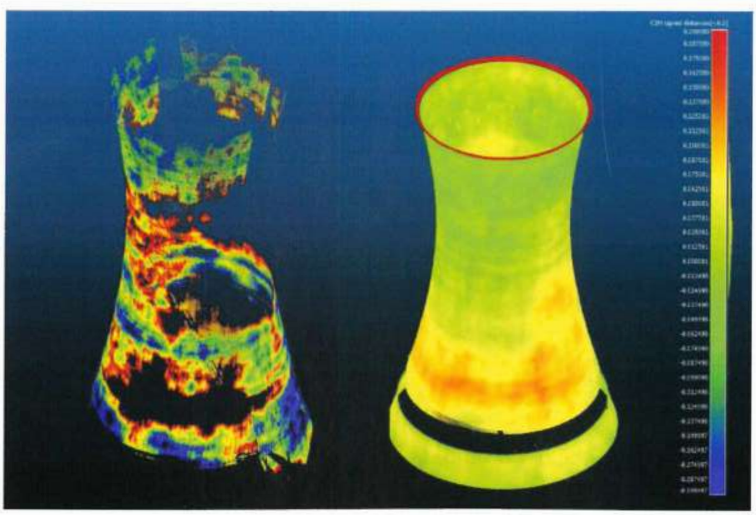

Fig. 6. Deviance analysis between the point cloud and the BIM model. Interior surface on the left and exterior surface on the right