DESIGNED IN ITALY
MADE IN AUSTRALIA.

The Australian work of

PIER LUIGI NERVI

CURATED BY **PAOLO STRACCHI**

THE EXHIBITION | SYDNEY 2019

VENUES

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11 July - 10 September, 2019

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NERVI ALGORITHM

ARTURO TEDESCHI

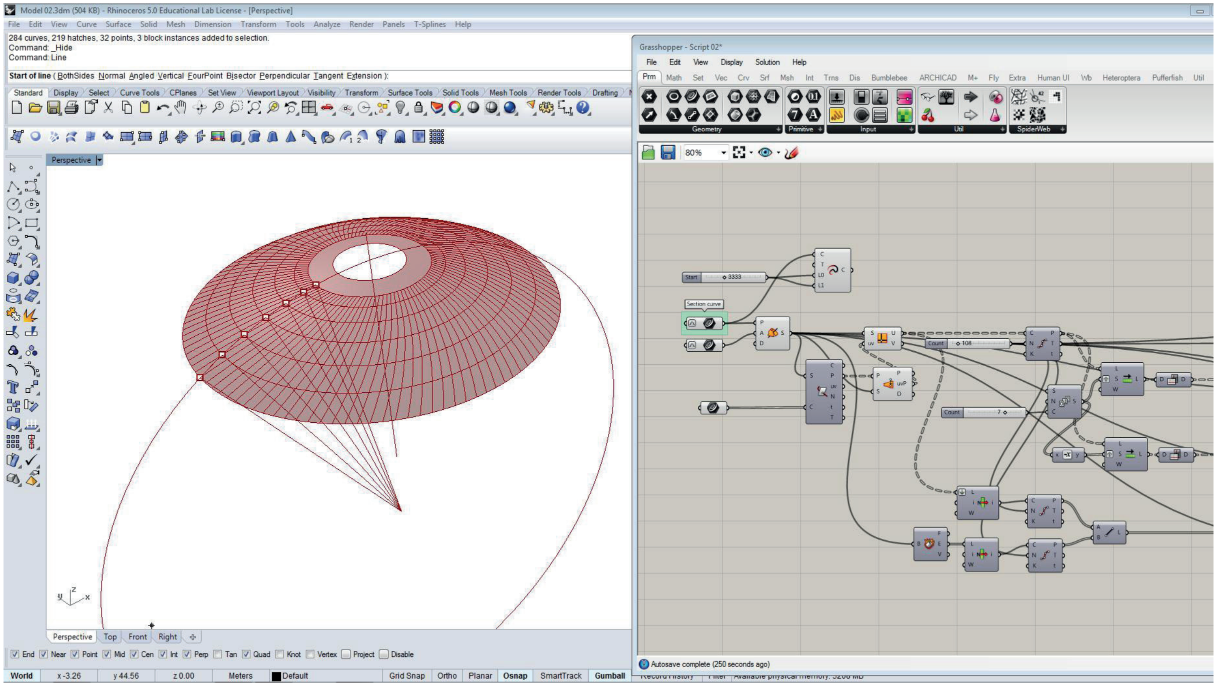
In the first instance, the word algorithm appears intrinsically connected to the execution of IT procedures, to the development of scripts and, in other words, to the use of the computer. Secondly, the attempt in identifying the etymology will probably (and erroneously) lead to the Greek term *rythmos*. History instead wants the expression algorithm to derive from the name of Muhammad al-Khwarizmi, a ninth-century Arab mathematician who revolutionised the resolution of complex mathematical and geometrical problems and who unknowingly became, centuries later, the father of computer science.

The algorithm is a sequence of simple, repeatable and unambiguous operations used to solve a more or less complex problem or to obtain a certain result. In other words, the algorithm is a mirror image of the innate human ability to break down a complex problem into a sequence of elementary steps. It is therefore not uncommon to be able to trace the application of algorithmic procedures in various fields of knowledge and research, clearly antecedent the birth of the computer and even before al-Khwarizmi himself. From a certain perspective, the algorithm brings humanity closer to nature and its intrinsic processes of optimization and efficiency.
In the field of architecture, for example, the avant-garde experimentations on thin shells (structures resistant for shape with minimum resistant thickness) have represented an exceptional field of research in the attempt to design and build according to the aforementioned principles. And if the first attempts have seen the abandonment of traditional instruments such as pen and pencil to the advantage of analogical simulations with membranes and soap films, today the computer opens up new perspectives: simulations and genetic algorithms have been part of the new designers' toolbox for about a decade. But, as we said, a certain algorithmic thinking is present in the research and professional activity of many masters and is certainly traceable in Nervi's work and in his unique construction system, the so-called Nervi System. The Nervi System is a set of technical solutions that define an economical and rapid way of building, aimed at creating complex shapes, optimized in terms of static behaviour and the use of material. The system also considers the construction phase as intrinsically linked to the design phase.

An example of application of the system is the construction site of the Palazzetto dello Sport in Rome, where Nervi designed a dome with crossed ribs that would have required too complex and expensive wooden formwork in the case of using ordinary reinforced concrete. Instead, he divides the surface with a statically efficient lattice from which follows a 'puzzle' of rhomboid and triangular elements to be used as geometrical matrices of one-way formworks: ferrocement panels. In fact, the cross-section of the planks provides four flaps that, once placed side by side, become the channels for casting the concrete and, in other words, the negative of the ribs themselves.
The Nervi System has been protected by patent n.465636 (1950) which certifies the 'rhomboid panel' and the

<< Palazzetto dello Sport, Rome, 1957
Photo Harry Seidler (cropped), 1964 © Penelope Seidler

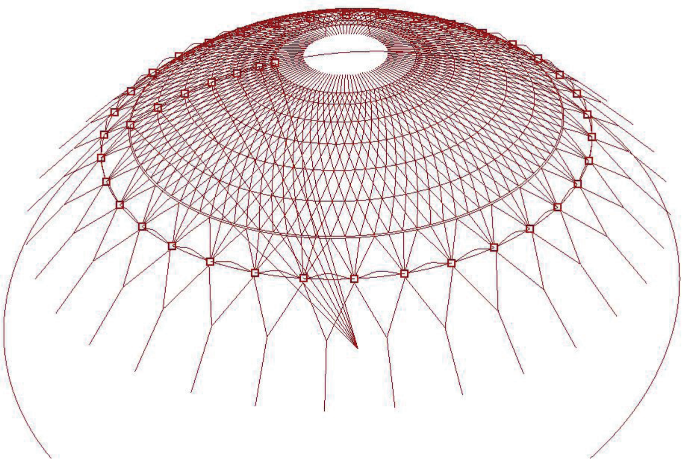
same generative process, that is the sequence 'grandmother, mother, daughter'. The aim and originality of the research presented in these pages lies in having translated the process of geometric generation of Nervi into a series of visual algorithms that can be performed within a three-dimensional modelling software. In this way, the digital models of some significant works of Nervi have been generated through an innovative process that essentially moves away from the mere relief and digital representation of the existing. In other words, the final shape of the buildings was not simply replicated, but somehow the generative DNA was extracted, the sequence of geometric operations used by Nervi was summarized and translated into visual code. This allowed, for example, to use part of the 'code' contained in the Palazzetto as a sequence of genetic bricks of part of the rib of the Mushroom in Sydney. The software used for this purpose is Rhinoceros, one of the most widespread and versatile three-dimensional modeling software based on NURBS mathematics and used in very different fields, from naval design to architecture. The potential of Rhinoceros is now extended by the algorithm editor Grasshopper, integrated by the 6.0 software version.

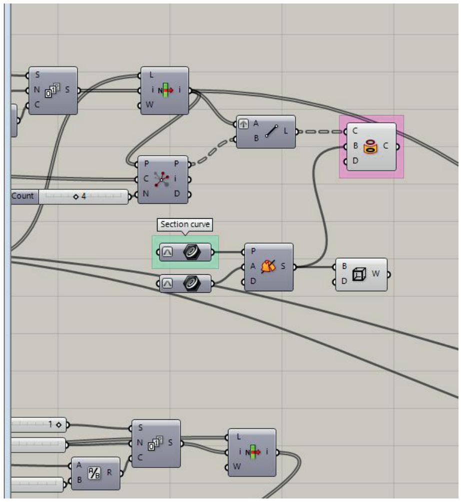


Grasshopper allows one to perform geometric operations inside the three-dimensional modeler without directly manipulating digital objects, but constructing algorithms in a visual way (i.e. without writing codes) using a node interface (previous and following image), whose blocks correspond to geometric primitives, transformations and complex operations on data.
The algorithms have been edited following a precise workflow similar to the Nervi System which, starting from the basic information gathered for each paradigmatic building, has included the following steps:

- Two-dimensional definition of the ribs (network of curves)
- Identification of the modules corresponding to the Nervi System panels
- Three-dimensional definition of the modules / panels
- Radial repetition of the modules / panels on the project surface

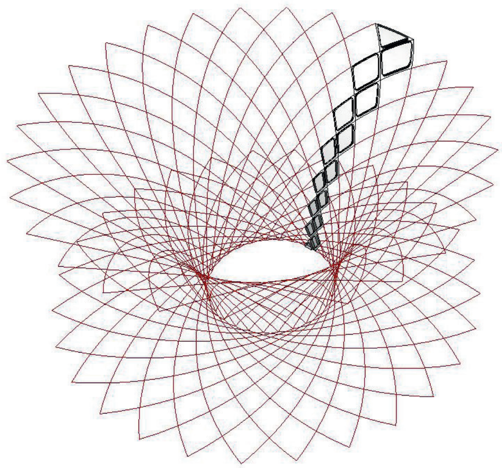
The following images show some screenshots taken from Rhinoceros/Grasshopper, related to the development of the algorithm for the Palazzetto dello Sport in Rome and for the Mushroom in Sydney.





The modularity and symmetry of Nervi's works makes the development of the algorithm linear and logical and allows all the elements of definition of the form to be linked in a single 'chain' system. In the Palazzetto model, the generation of the vault profile is linked to the identification of the beams that intercept the base curves for the construction of the rib wireframe and, in cascade, all other subsequent development elements. The possibility of inserting within the algorithm specific components able to manage data matrices, drastically simplifies the construction of the intersection points of the lattice and the generation of the ribs.

In the initial phase the algorithm is structured to construct the wireframe of all the characteristic elements of the geometry, then move on to identify the set of modules to be repeated in a radial sense. The modules are constructed starting from the wireframe and developed as three-dimensional surfaces (see fig2). This step is one of the most complex and not without its criticality due to the need to manage offsets in different directions and having to comply with rules of continuity between multiple surfaces. However, this top-down method allows a perfect adherence of all the modules once the polar array has been executed with the consequent possibility of joining the replicated elements in a single watertight poly-surface.



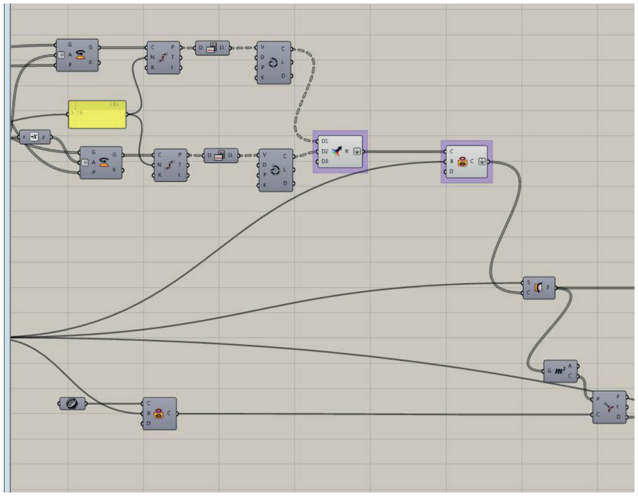


Fig.1. Module identification and three-dimensional development starting from the two-dimensional grid.

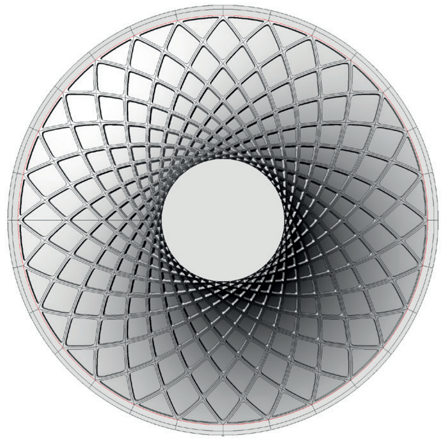
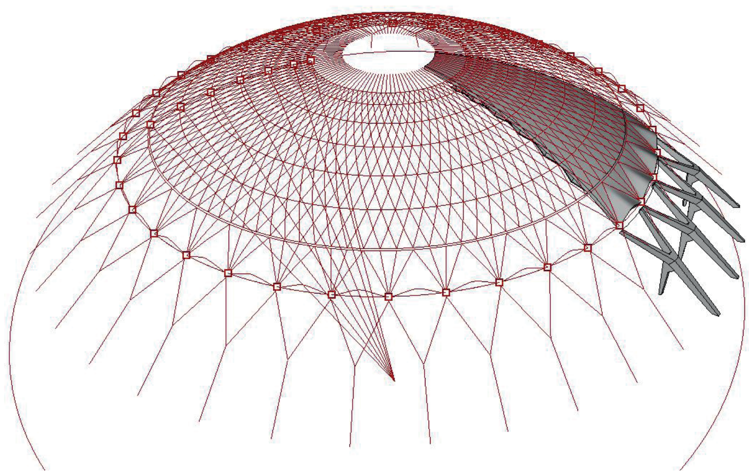
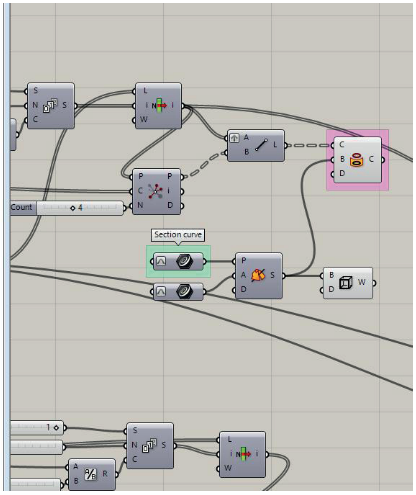


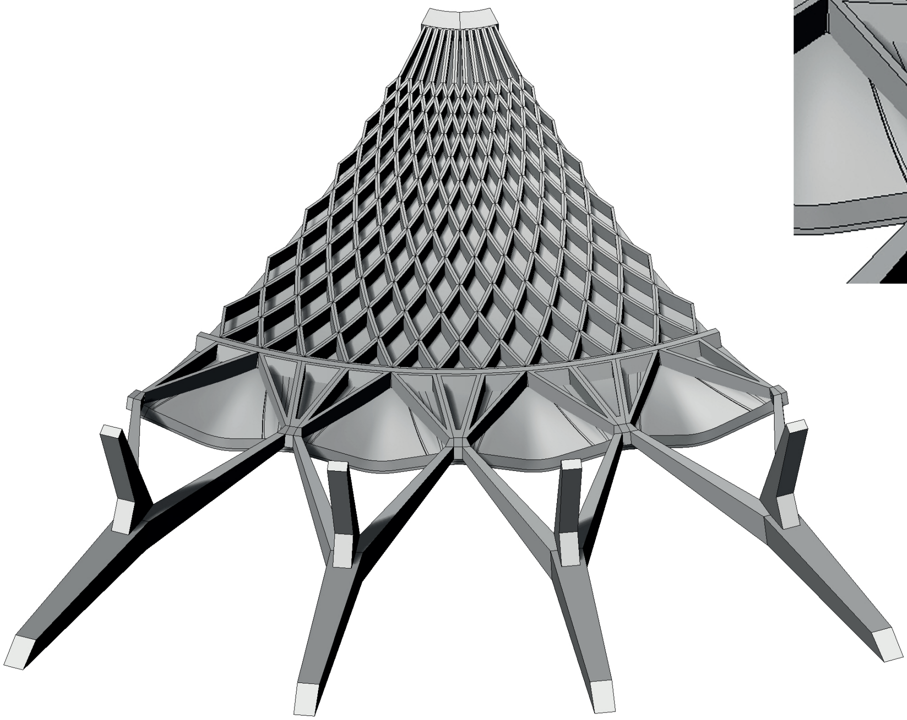
Fig.3. The polar repetition of the modules generates a single seamless poly-surface (watertight geometry).

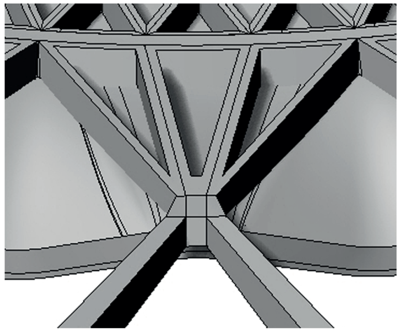
The major critical points of the algorithmic logic are to be found in some variations to the rule present in the geometric schemes. In the Palazzetto, for example, it is necessary to reshape some three-dimensional selection and development criteria in the areas where the network meets the outer ring thus generating triangular modules. Even more complex is the management of 'eyelid' surfaces and of the relative sub-structure with branches (see subsequent images). The 'trestles' are built starting from the axis lines obtained from the overall network and developed three-dimensionally respecting the fidelity to the real model: the individual surfaces that constitute the sides of the trestle are always planar (in reality this feature makes these structures achievable with flat formworks), therefore constructed with more complex techniques of loft between surfaces (which do not guarantee the flatness of the surfaces obtained).





Finally, the efforts in terms of algorithm construction with regard to the definition of some geometric nodes, such as that between the stand and the branches, as shown in the following images, are not secondary.





AUSTRALIA SQUARE TOWER – ALGORITHMIC WORKFLOW

In this section we intend to show the complete workflow for the generation of the design version of the Australia Square tower in Sydney. The process involves the development of an algorithm faithful to the methodology of conception of Pier Luigi Nervi's form. In particular, the structure of the floor is generated through the polar repetition of a set of panels of defined shape and size .
In the specific case, the basic network results from the repetition of seven modules of different shapes and sizes (3 rhomboid and 4 triangular) .

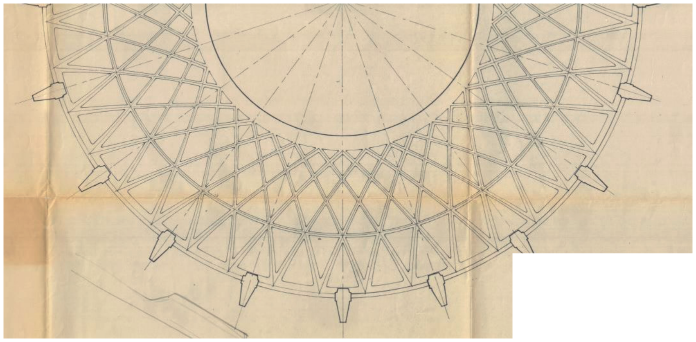


Fig4. The design version of the Australia Square Tower floor differs from that realized for the geometry of the ribs and for the absence of the flaring in the panels

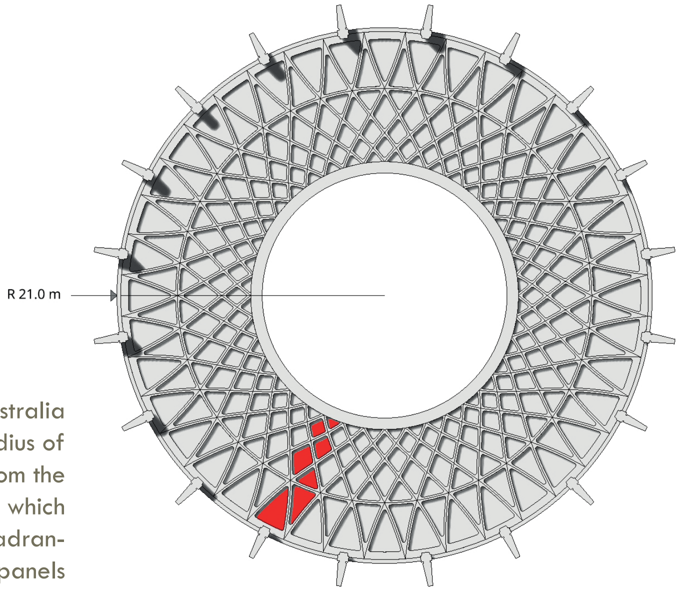
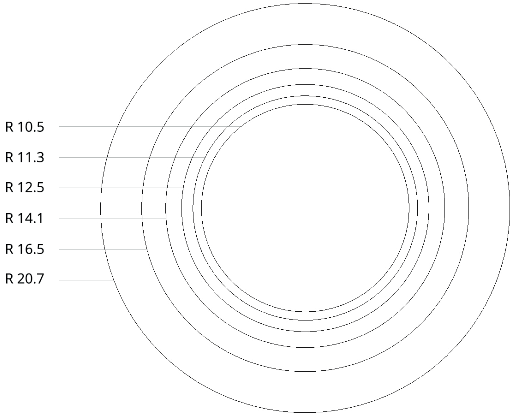


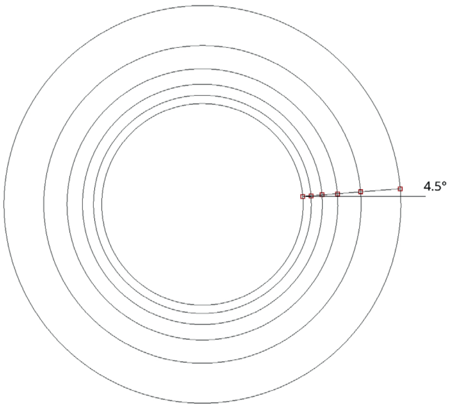
Fig.5. The design version of the Australia Square Tower floor slab has a total radius of 21 metres. The ribs are generated from the radial repetition of seven modules, of which four are triangular and three are quadrangular.absence of the flaring in the panels

1. CONSTRUCTION OF THE TWO-DIMENSIONAL LATTICE

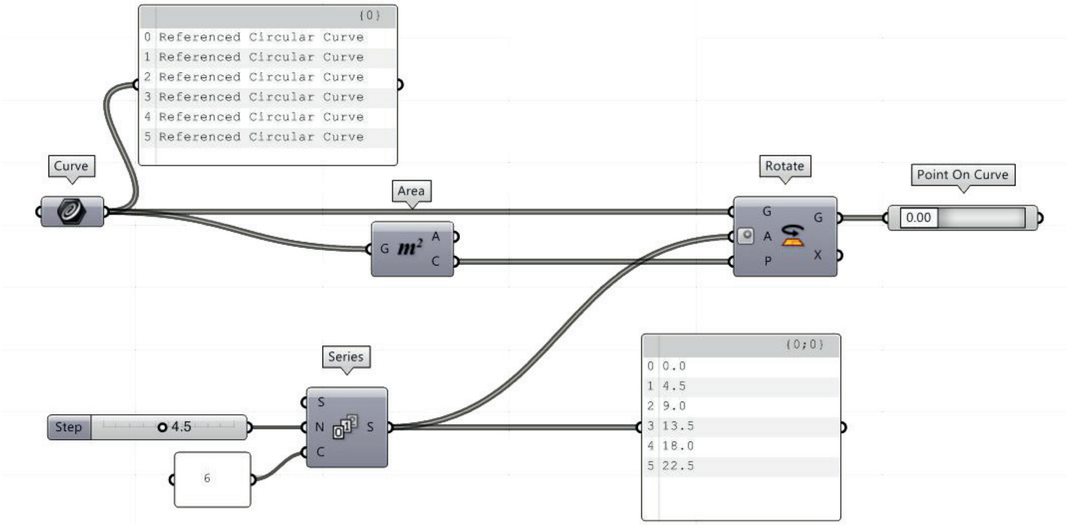
1.1. The modules are not geometries a-priori defined but result from the creation of a geometric lattice obtainable through a precise geometric construction and designed by Nervi to satisfy specific structural performances. By algorithmically developing this construction, the initial step is to draw six circles whose radius is derived by measuring the distance between the centre of the floor and the intersection points of the lattice. The largest circumference has a radius of 20.7 metres which, added to the 30 cm of the perimeter curb, returns the total radius of the even floor, precisely at 21 metres.



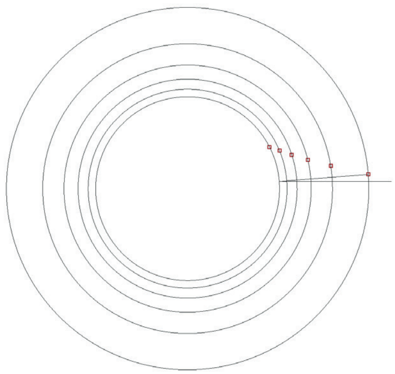
For a faithful reconstruction of the lattice through the algorithm, the circumferences must have their own seam (in Rhino the closed curves have a starting point coinciding with the final one, defined precisely seam) aligned according to an angle of 4.5 degrees as shown in the following image. This alignment can be achieved through a set of components in Grasshopper or by manually changing the start point of the curves in Rhino.



1.2 The next step involves a progressive rotation (Rotate-Plane component) of the circumferences, using incremental rotation values of 4.5 degrees, with zero initial rotation. The six circles will rotate 0, 4.5, 9, 13.5, 18, 22.5 degrees respectively.

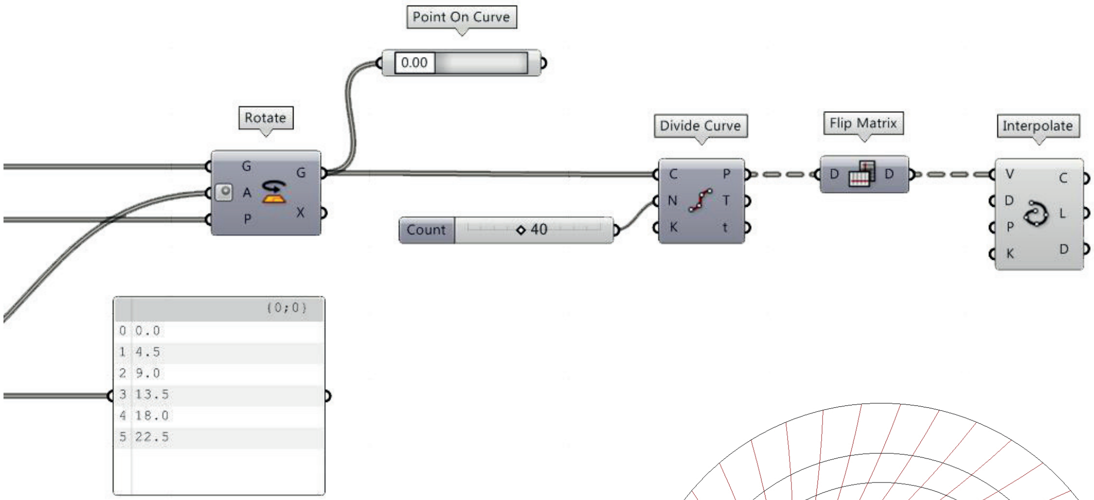


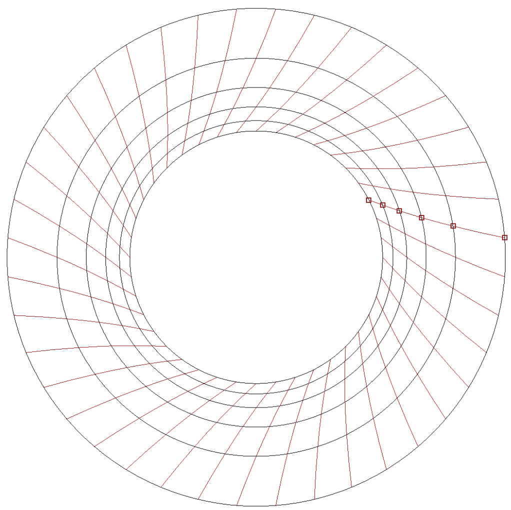
The seam of the rotated curves (points highlighted in the following image) can be verified through the Point on Curve component set to zero (start point).



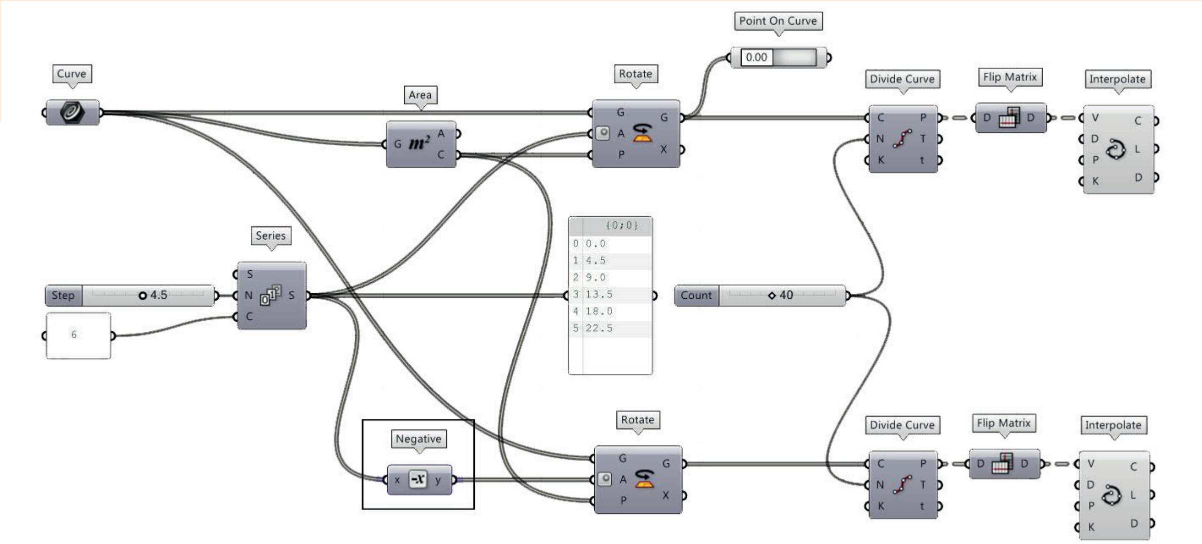
1.3. At this point it is possible to subdivide the six circumferences into 40 parts, obtaining as many points arranged according to the definitive lattice.

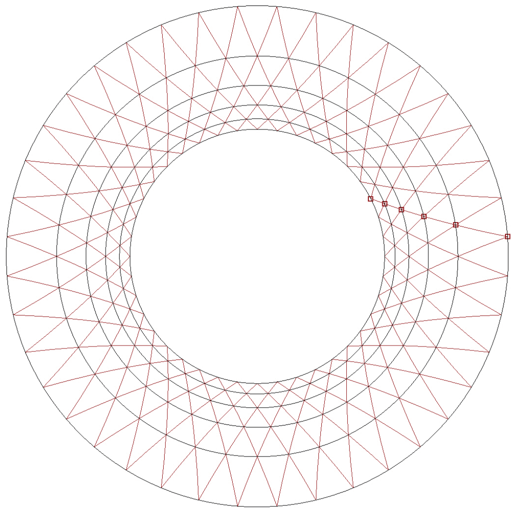
The algorithmic approach allows us to trace the first set of curves through a matrix logic such as to make it possible to create a single curve as a connection of corresponding points on different circumferences (following images). Flip Matrix and Interpolate Curve return the first system of curves, perfectly superimposable to the original design of Nervi.





1.4. To be able to create the second set of curves, it will be sufficient to rotate the curves using the previous angular values, but changing the sign, thus rotating in the opposite direction. The lattice is therefore completely defined.

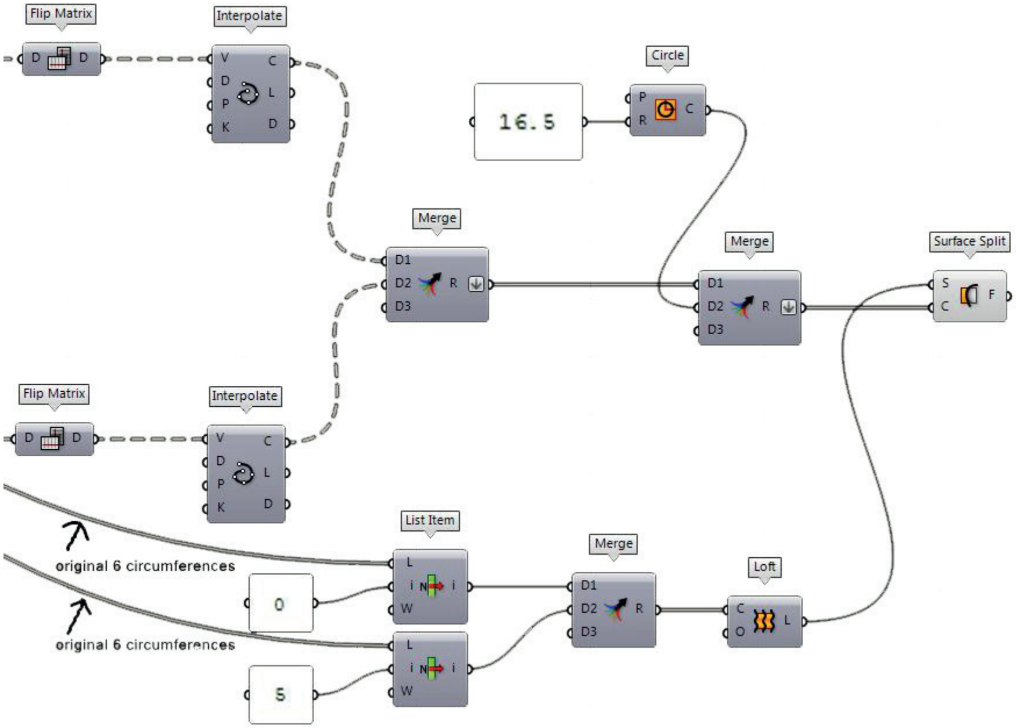




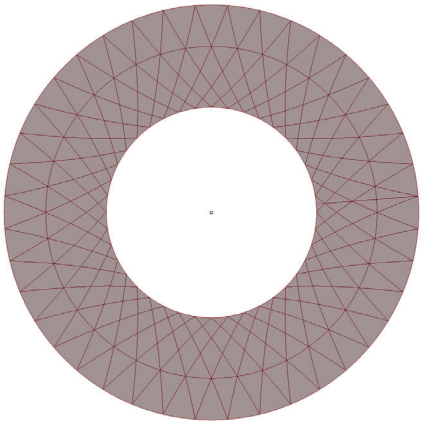
2. OVERALL IDENTIFICATION OF THE MODULES

2.1. Although already geometrically and visually identifiable, the modules do not yet exist from the data point of view. In fact, the curves that define the lattice are single overlapping elements, and the modules represent the empty space between them. In other words, our eyes perceive these spaces, but they do not exist as entities within the algorithm. It is therefore necessary to make the computer 'see' the same way.

For this purpose, we build a surface corresponding to the entire floor, obtained as a loft between the major and minor of the six initial circumferences (selected through two List Item components set to i = 0 and i = 5).
A cutting operation (SurfaceSplit) of the loft surface is then performed with the previously obtained lattice. According to the design of Nervi, it is necessary to insert in the set of curves the circumference of radius 16.5 (see paragraph 1.1) which can be retrieved from the initial set or recreated as in the following diagram.

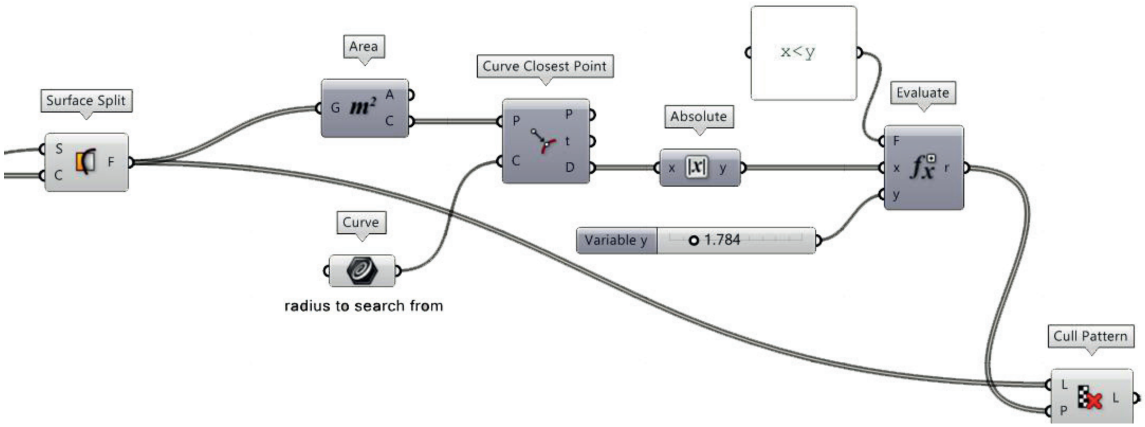


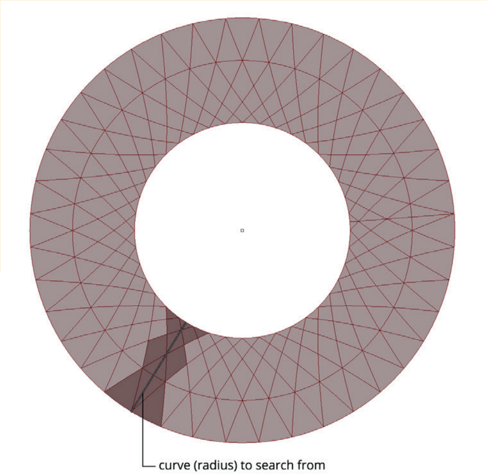
The result of the operation is a set of 284 triangular and rhomboid surfaces corresponding to the searched modules.



3. IDENTIFICATION OF THE 7 BASE MODULES

3.1. Within the overall set it is necessary to identify the 7 modules at the base of the polar repetition. The strategy used involves the identification of a curve-radius of the floor and the search for the modules closest to that curve. The operation, performed through the Curve Closest Point and Evaluate component, returns 12 modules, i.e. the 7 basic modules and 5 symmetrical modules with respect to the radius. Through a subsequent selection operation (List Item) we can easily select only the 7 modules required, 3 of which are rhomboid and 4 triangular.





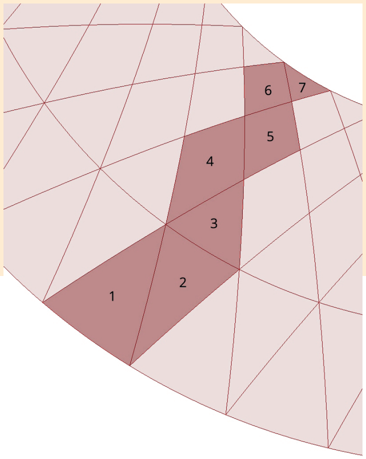
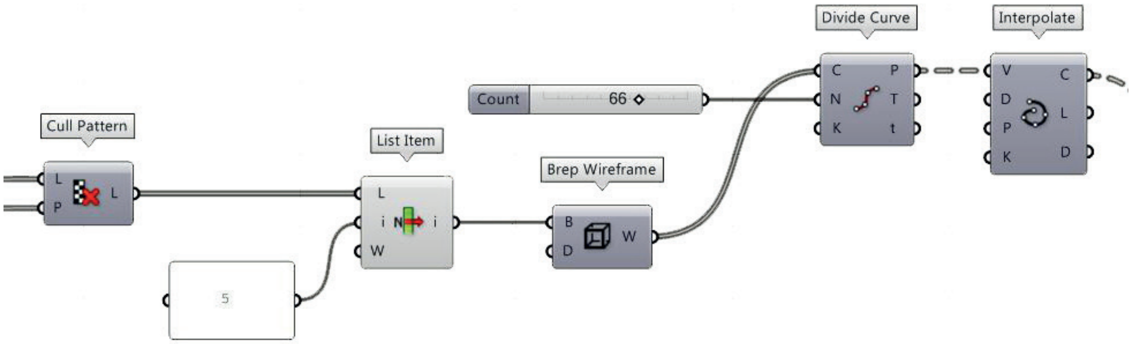


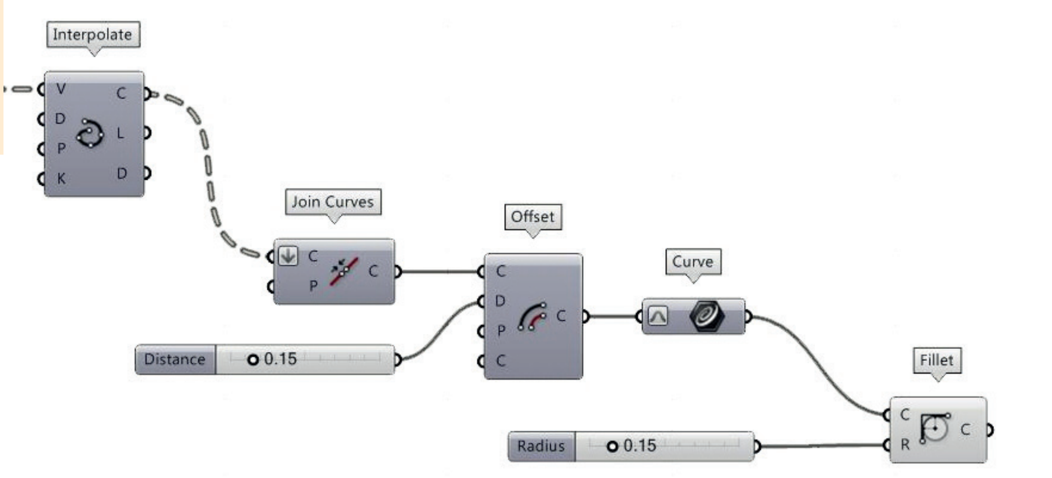
Fig.6. The use of a criterion of proximity to a curve-radius allows to find 10 modules including the 7 basic modules and 5 symmetrical with respect to the curve itself. Through List Item it is possible to select the 7 modules at the base of the construction of the final grid.

4. THREE-DIMENSIONAL DEFINITION OF TRIANGULAR MODULES

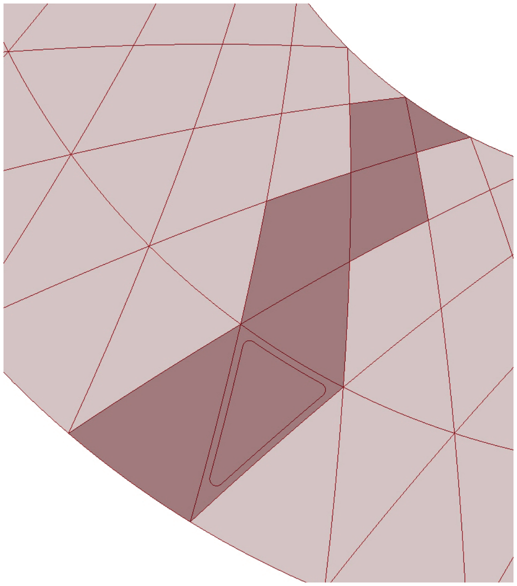
4.1. Using the List Item component we can select the triangular module #2 (see previous image) and perform the entire set of operations such as to transform the flat surface into the complete three-dimensional module. The surfaces obtained by cutting the starting surface with the network of curves need to be 'reconstructed' so as to pass from trimmed geometries to untrimmed geometries. This operation does not change the shape of the surfaces, but only the mathematics of the same. It is, however, a fundamental operation for the subsequent developments of the algorithm. As a first step, the three edges of the surface are extracted through the Brep Wireframe component and reconstructed by dividing the starting curves (Divide Curves) and interpolating the subdivision points (Interpolate Curve).

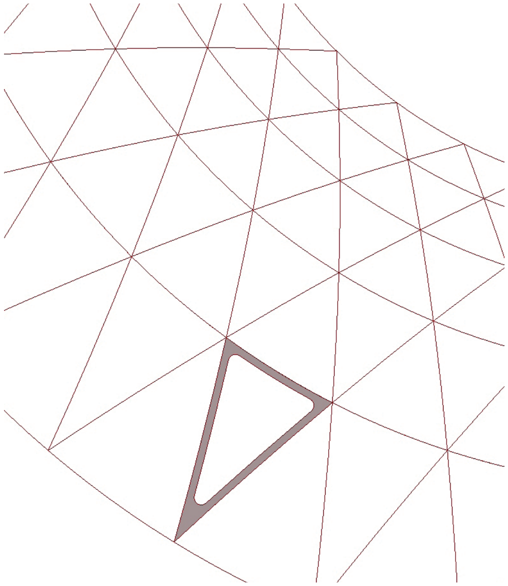


The three curves thus reconstructed are joined (Join Curve) to then receive an offset of 15 cm .

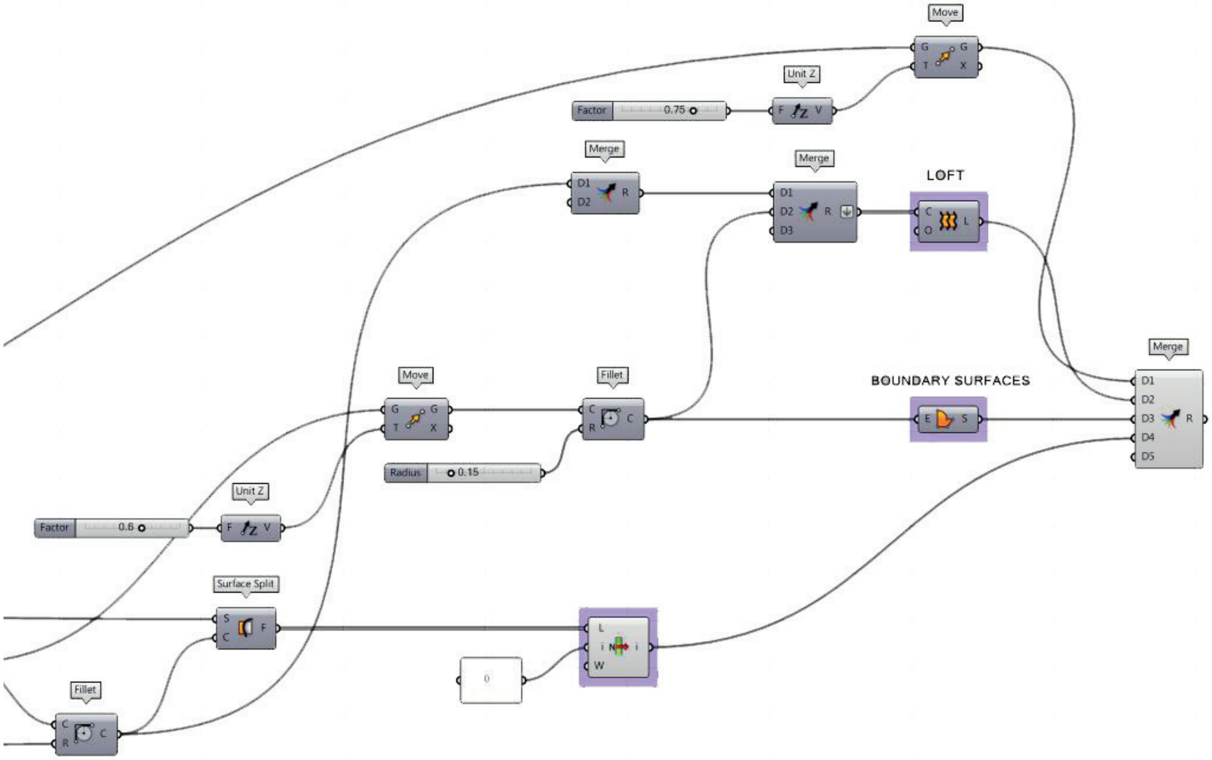


Through the Fillet component, the fitting with a 15 cm radius is realized as per the project.





4.2. The final curve thus obtained is used as a cutting curve for the triangular starting surface and is further extruded in the vertical direction with an extrusion length of 60 cm. The surface thus obtained is capped at the top using the Boundary Surfaces component. As a final step, the triangular starting surface (uncut) is copied with a 75 cm displacement in the vertical direction.



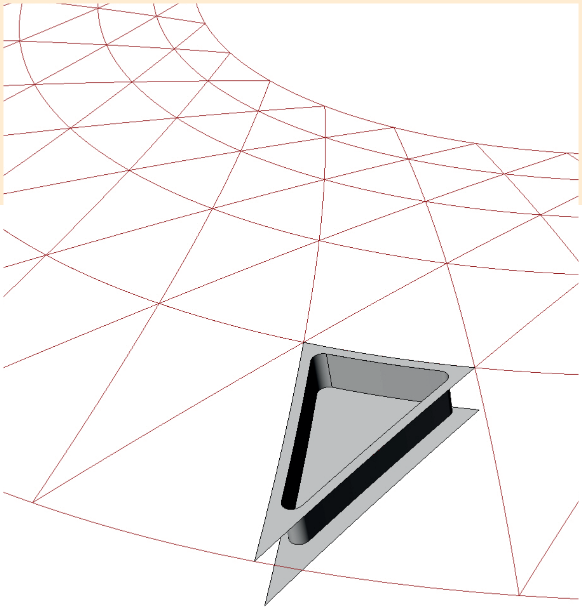


Fig.7. The base triangular module consists of a triangular surface and a poly-surface (Brep) obtained by welding the extrusion surface and the triangular cut surface.modules at the base of the construction of the final grid.

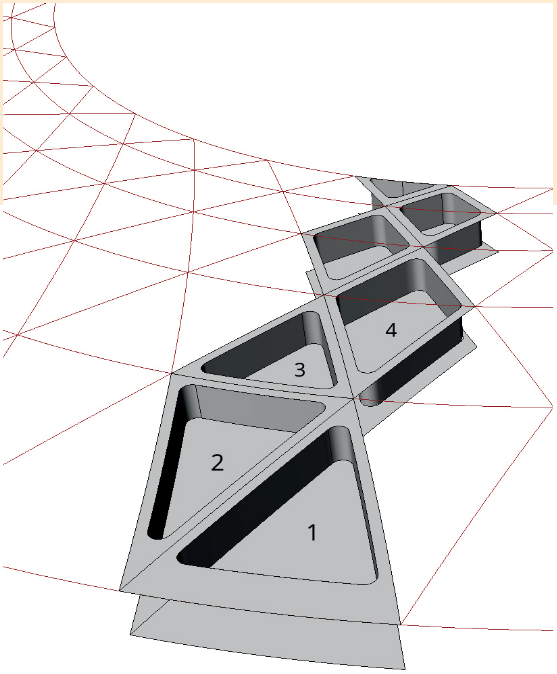


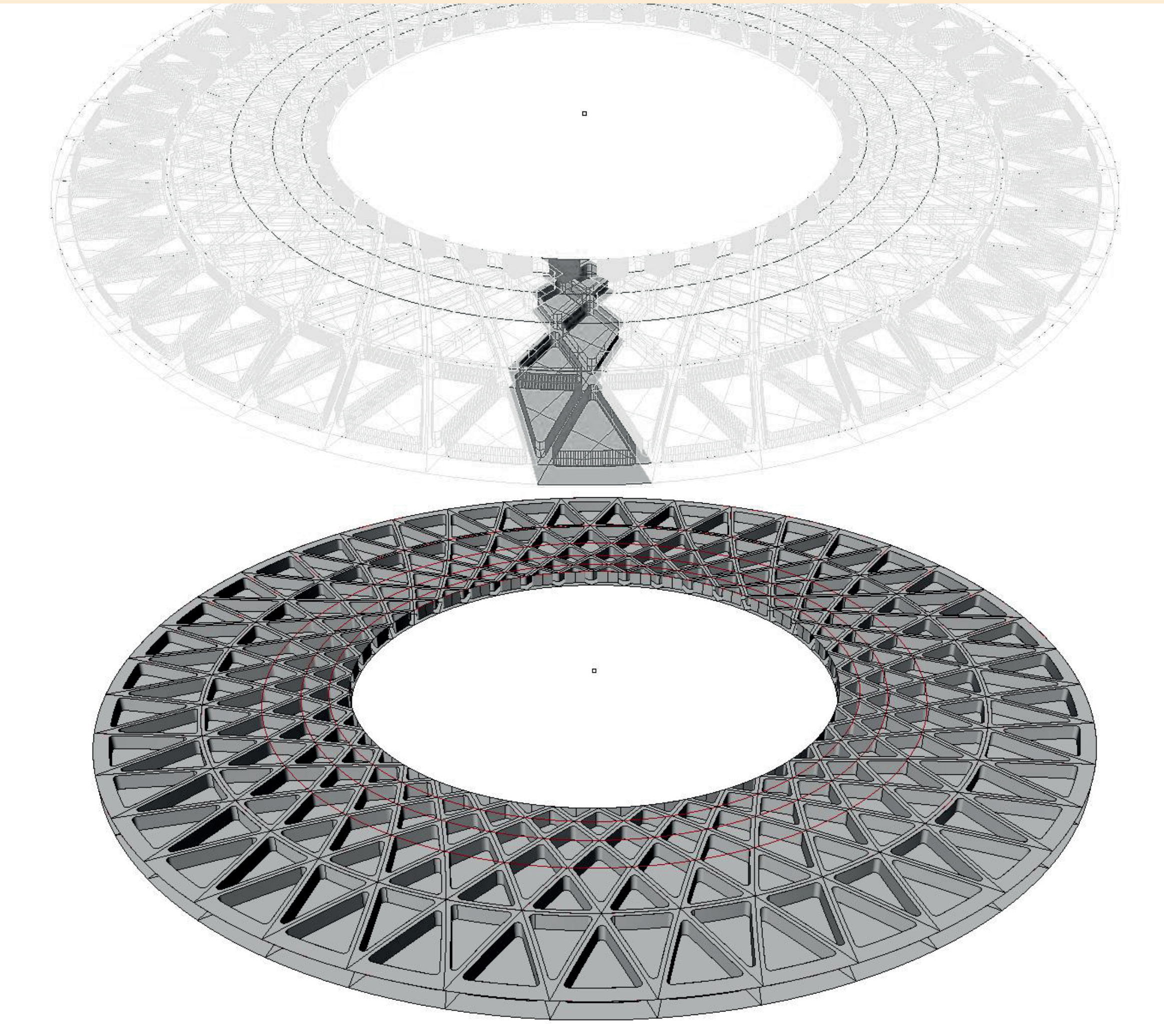
Fig.8. The use of a criterion of proximity to a curve-radius allows to find 10 modules including the 7 basic modules and 5 symmetrical with respect to the curve itself. Through List Item it is possible to select the 7 modules at the base of the construction of the final grid.

5. THREE-DIMENSIONAL DEFINITION OF RHOMBOIDAL MODULES

5.1. The definition of quadrangular modules does not differ from the methodology used for triangular ones. In the previous image, which shows the panels from the lower viewpoint (opposite to the diagram in fig.3) , the 7 complete modules are visible, whose radial repetition will comprehensively generate the soffit and the extrados of the floor.

6. RADIAL REPETITION

6.1. Radial repetition can be performed through the Polar Array component in Grasshopper or by using the Polar Array command in Rhino using the vertical axis passing through the centre of the slab as the rotation axis.



7. DETAILS

7.1. By virtue of the process followed, the repetition of the modules guarantees the perfect adherence of the generated geometries. From the computational point of view this translates into a set of two watertight surfaces that can be completed through two cap surfaces obtained as a loft between the curves of the floor edge. The solid thus created is completed by the modelling of the pillars (of which only a portion of the vertical development is constructed). The Boolean union of the geometries generates a single closed poly-surface without any open edge.

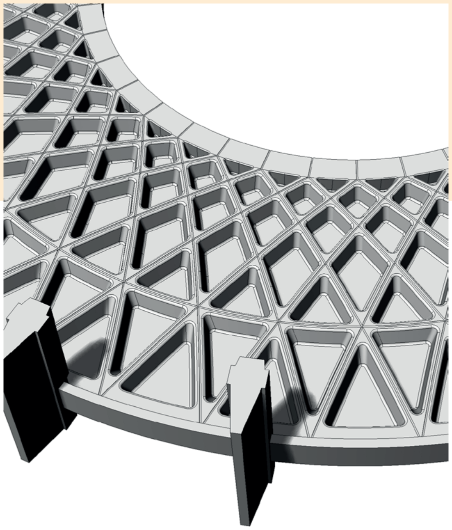
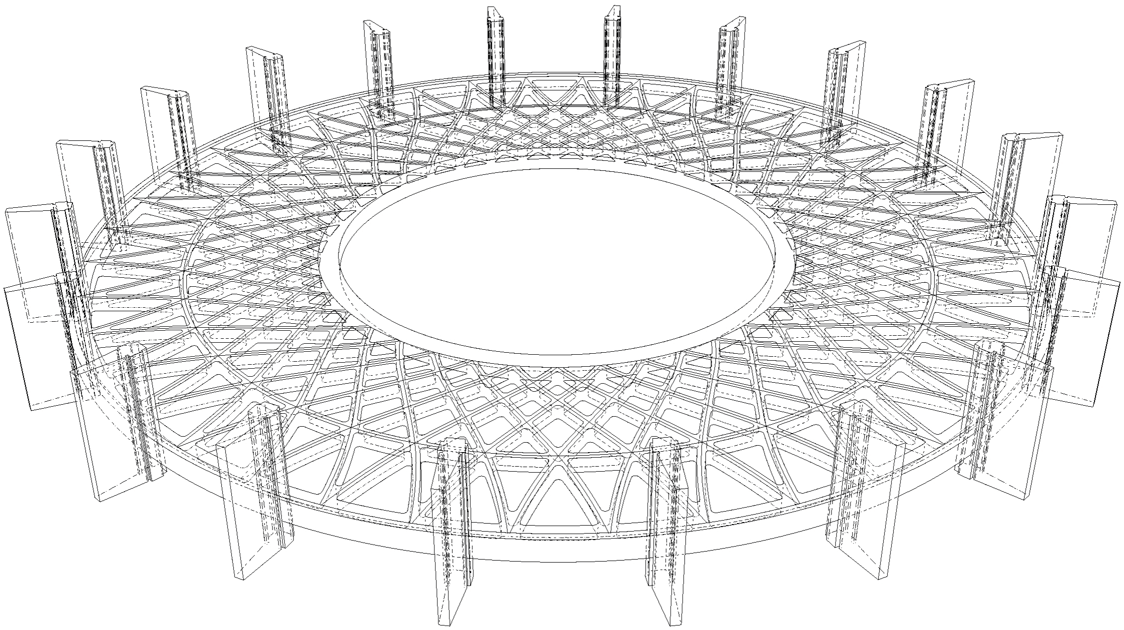


Fig.6. The image shows the realized version of the Australia Square Tower floor slab, where the different details (grooves, flarings) are obtained with additions and modifications to the basic algorithm.



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