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Temporariness and durability in contemporary architectural design

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The “temporary” state in architectural design has become one of the most interesting issue in the field of building construction. At the same time, in contemporary architecture, the concept of sustainability is strongly linked to that of durability, which itself is linked to the used materials. For materials being durable means basically to save resources. The natural stone, which has high durability, is currently having a moment or “renaissance” in which it is being used in new shapes and expressions. In this research, the masonry structures, typical of stone architectures, are considered a focal point in the design of temporary structures. To achieve this objective, we have to investigate the field of resistant structures for shape. This paper reports the study of a temporary stone structure, modular, able to cover large areas with a reduced use of supports, easily disassembled and reassembled for other purposes, designed to be adaptable to the most varied demands for “high quality” spaces.

Key words: pre-stressed masonry, dry assembled, stone, shell shape, temporary architecture

1 Introduction

In contemporary cultural debate, several instances characterize the architectural design. That which is present, within these issues, is research’s aim that identifies new design which is referred to two particular instances as temporariness and sustainability.

Within research reported in this paper, the design of an innovation structure will be studied in which temporary and sustainability must be tied together. In particular, the design seeks to meet a growing demand from the market of temporary structures. These can be used as a uniform coverage for high-quality flexible open spaces for creative activities (exhibition spaces, outdoor markets, refreshment areas) able to offer reversibility, recyclability for new uses, flexibility and aesthetic quality. These must be adaptable to various needs, as well as be modular and capable of covering large spaces thanks to a reduced use of points of support.

Innovation includes utilization of a sustainable material as natural stone in a temporary structure and therefore removable in all its parts. In fact, natural stone is characterized by high durability and, traditionally, it is linked to massive constructions characterized by high weights.

Weight and weightiness, strictly linked to the concept of durability and sustainability, are considered a focal point in the design of temporary structures. The challenge is to combine the idea of weight and gravity with that of being temporary. The present paper reports a solution to these issues that lies on the design of a temporary modular base structure in natural stone that can be repeated in various ways, to take on the planned configuration and extension. To do this, research has deepened previous experiences on issues concerning: temporariness and sustainability, reinforced masonry and double curvature vaults.

1.1 Temporariness and sustainability

In the last years, the “temporary” state in architectural design has become one of the most interesting issues of the cultural debate, in the field of building construction. The “temporary” buildings are architectural “products”, such as single-family houses, micro structures and installations, made to last a certain length of time. The adjective “temporary” is opposed to the condition of permanence that has always characterized the object or the artefact building, made to “stand the test of time”. The temporary is a constitutional element of modernity and it has been elaborated by architecture to the point of it being declared a driving force for a project: in 1851 the Crystal Palace in London contained in its program the reasons for its compulsory dismantling to justify the main reason for its dry assembly. Initially, the temporary architecture was the unexpected key to experiment – on a small scale – the technological and language innovation that would have then flowed in their luckiest buildings such as Mies van der Rohe in the German pavilion (1923) in Barcelona.

In the temporary architecture at Expo 92 in Seville, designed by Martorell, Bohigas and Makay, Peter Rise for the first time, experiences the matching between stone and steel in the realization of 11 arches that bear the roof of the pavilion of service.

Today the conditions seem to have radically changed. The technology at the service of effects has scaled down its reasons to the mere aesthetic dimension taking temporary architecture back to the vision of the celebratory machine. Temporary architecture is therefore a proper and complete architecture but with a limited destiny.

Every time you design architecture works for limited events, the problem arises afterwards, buildings that should inevitably self-destruct at the end of the event, may have a longer life. Why not think of further use, why not leave something that was created with an ephemeral opportunity, but that may work for many, many years yet? The predisposition of solutions which are suitable to change over time to be reused for other events can certainly reduce the outflow of resources in the light of sustainability. The topic of sustainability crosses the theme of temporary because it can provide the base for a better resource investment.

As contemporary architecture, temporary architecture is more and more geared to equate innovation with sustainability. These are the two keywords underpinning temporary architecture in the name of environment-friendly construction. Temporariness is joined with a sensitive approach that is able to determine the inter-relationship between the environment, its resources and the person that creates durable works of architecture. At the same time, these structures are designed to have a life affiliated with the period in which they are presumably used.

The predisposition of technological solutions which are durable and suitable to be transformed can certainly reduce the cost of these transformations. So it is very important to introduce sustainable designs able to reduce these kinds of energy, strongly linked to the used materials. For materials, being durable means basically to save resources. The building materials have a high price of recycling, in our system and, so, in the light of sustainable development, the optimization of the material’s life cycle (mode of production and disuse) is a higher priority compared to the linear maximization of functions (performance of each material).

For temporary architecture, usually, the construction typology must respond to the requirements of lightness, simplicity, rapidity and easy installation - dismantling in addition to an overall low cost of the intervention.

Most experimentations and research have the aim to achieve real or simulated transparencies, reduce thickness, materials and bulk. Sometimes, however, the principles of lightweight applied to any function and geographical context do not always generate sustainable solutions with negative effects in terms of energy and environmental costs. Moreover, the innovation considers the weight as a feature to eliminate and an enemy to escape: weight and weightiness are shunned by temporary architecture.

But weight in architecture has undeniable advantages. The solidity of weight is reassuring, a natural phenomenon determined by the very laws of gravity. The concept of durability is frequently associated with massive building elements whose reliability and durability have been tried.

Today there is room to still work with weight, giving new meanings to this term and using heavy materials through new technologies and with greater environmental and formal awareness. There is no reference to technical innovations that can reduce what is heavy, resulting in misunderstandings about the true nature of the materials, such as stone sliced and reduced to a simulacrum of itself, pasted on the honeycomb lightweight aluminium supports, depriving it of its elegance and sense of solidity. However, reference is made to an innovation that combined with cultural realities is liable to give back to new architecture that sense of need and truth that the historic towns that we handed down today which is often lost in contemporary architecture.

According to the new ideas coming from a sustainable development, a traditional material like the natural stone, in fact, is a sustainable material “in itself” aside from the specific ecological qualities made possible by technical transformations [3] first of all for its high durability and capacity to “age well”. The chief quality, which in some ways encapsulates all the qualities of sustainable material, is duration [6]. For materials, to be durable means basically to save resources.

The stone is able to accomplish, on its own and consistently in long periods of time, diverse tasks (duration, aesthetic characteristics, environmental value, building reliability, static security, endurance, protection from atmospheric agents, thermal and acoustic protection, fire resistance, etc.). The stone-working does not produce emissions; moreover, it does not generate waste that must be taken to landfills; all the scraps processed can be re-utilized or used to redevelop the quarry. The natural stone has a high level of durability so as to permit some cycles of reuse during its life.

History provides numerous examples of this in stone construction. Many second-hand elements plundered from other buildings were reused in the façade of St Mark’s in Venice. The Forum Romanum provided a great “quarry” for Renaissance builders. In the Middle Ages, the Etna basalt blocks plundered from the Roman Amphitheatre were reused in the building of the fortification walls in Catania and, after, in the 16th century, again reused to rebuild the town destroyed by the earthquake in 1693.

Great historic monuments in the world like the Pyramids and the Great Wall of China, are examples of physical and cultural durability of this building material. For this reason, many building projects employ heavy materials, such as natural stone, in new and interesting ways that also hark back to ancient structural traditions.

Peter Rice, was interested above all in the structural aspects of the use of stone. The experience of matching stone and steel, in the cover of the service pavilion at Expo 92 in Seville, later, was resumed by Peter Rise in the sanctuary of Padre Pio in St. Giovanni Rotondo, designed by Renzo Piano and in the new façade of the Basilica of Notre Dame de la Treille in Lille. These structures are characterized by high slenderness and great mechanical strength.

Rice played a major role in developing the concept for the huge pilgrimage church of San Giovanni Rotondo in Foggia by Renzo Piano (2001). Here the newest technology was applied to the construction of the stone supporting arches, which have spans of up to 50 metres. The space of the Sanctuary is characterized by a double range of arches, realized with blocks of local stone (Apricena) of various sizes. The use of highly resistant materials to compression, such as natural stone, with the addition of fibres or metal reinforcements, improves resistance to flexure and cutting of the structures. The arches are subject to a pre-compression after the assembling phase with steel strands. So, to enable the assembly each block is perforated lengthwise with four holes corresponding to the edges and by two holes of bigger size, set along the longer axis of the trapezoidal section so as to contain the pre-compression cables. The difficulty of the project was the high number of unique blocks (about 1000) with characteristics of both formal size (slope faces) different from each other and the cuts with high precision and tolerance of less than 0.5 mm.

The contemporary reinterpretation of the ancient magisterial stereotomic (related to the science of cutting stones for the construction of structural devices) is a viable productive condition thanks to recent innovation in industrial production.

In the last years, new levels of mechanization have allowed for an industrial production (for analogue series) for which the objects are rendered on the basis of easily editable operational lines.

The advent of CNC machines, capable of shaping stone materials by taking the processing parameters directly from digital prototypes of parts to be made easily, allows you to easily make even 1000 different blocks.

The technological development, which occurred in the last two decades, today offers greater possibility to establish a new way of working with the industry. This allows you to explore the potentiality of traditional materials, such as natural stone, to develop innovative solutions, to utilize products that industry and designer will develop.

A new dimension of technological craftsmanship has been defined by Renzo Piano as “cultured and equipped” and it is based on the intrinsic nature of the materials and on basic construction principles. So, engineers and architects work on the production methods, realize prototypes to test in the work of architecture. The innovations made by numerical control machines to working stone, at different stages, and its physical-chemical and mechanical properties make it a current and sustainable building material [4].

1.2 The reinforced masonry

Based on P. Rice's experiences, at the Department of Civil Engineering and Architecture of the University of Catania, research was started with the objective to study a new constructive procedure. The research has aimed to redefine traditional masonry in natural stone with recent innovation aimed at dematerialization through the reduction of structural weight without altering the very nature and character of structural masonry.

The new procedure consists of a reinforced masonry, using natural resistant elements made of blocks of natural stone inside of which it is possible to insert special internal steel reinforcements to absorb the traction and cutting stress induced by dynamic actions according to the structural requirements (Figure 1).



Figure 1 Reinforced masonry in natural stone

From a mechanical point of view, the results obtained from the theoretical research and confirmed by the experimental phase, through laboratory tests (Laboratorio Ufficiale Prove Materiali of University of Catania), showed good performances of new reinforced masonry (Figure 2 and Table 1).



Figure 2 Reinforced panel, tested in diagonal compression, after breakage

Table 1 Mechanical characteristics of reinforced masonry blocks of Etna basalt

| Material | $f_{b,k}$ [kg/cm ²] | $f'_{b,k}$ [kg/cm ²] | M_i | E [kg/cm ²] | G [kg/cm ²] | dutt. | γ [kg/cm ²] | f_k [kg/cm ²] | f_{vko} [kg/cm ²] | $f_{k,tab}$ [kg/cm ²] | $f_{vko,tab}$ [kg/cm ²] |
|----------|------------------------------------|-------------------------------------|-------|------------------------------|------------------------------|-------|-----------------------------------|--------------------------------|------------------------------------|--------------------------------------|--|
| Basalt | 1500 | 1300 | 1 | 600000 | 24000 | 9,9 | 2700 | 600 | 12 | 143 | 2 |

- $f_{b,k}$ characteristic resistance of the material in the orthogonal direction respect the deposition of the mortar
- $f'_{b,k}$ characteristic resistance of the material in the parallel direction respect the deposition of the mortar
- E Young's modulus of the mortar
- G modulus of modulo di elasticità trasversale
- dutt. Ductility of masonry
- γ Weight density of the masonry
- f_k experimental characteristic resistance of the masonry with compressive stress
- f_{vko} experimental characteristic resistance of the masonry with cutting without compressive stress
- $f_{k,tab}$ characteristic compressive resistance of the masonry computed by using standard tables
- $f_{vko,tab}$ characteristic cutting resistance of the masonry computed by using standard tables in absence of compressive

The behaviour of the diagonal collapse, which allows us to define the resistance referred to in the horizontal solicitations, is quite different when comparing the masonry reinforced panels with the not reinforced ones. In fact, in the last case the collapse occurs in the plates of mortar: the collapse is fragile; while in the reinforced panels the valuation of the crack is progressive due to the mechanisms of the mesh between the natural stone (basalt) blocks and the steel bars. In summary we can conclude that the proposed construction procedure is quite suitable to be used in a seismic area due to the ductility requirement.

Results obtained from a second phase of theoretical research, and confirmed by the experimental phase, have shown that, due to the high compressive strength, the stone can be made into load-bearing masonry, in dry-assembled and pre-stressed stone blocks, improving the performance of the panel. The creation of a full scale prototype (a stone sail) has shown that the pre-tensioning action allows you to also compensate the cutting and traction stress due to the seismic and wind action for load bearing masonries of small thickness.

The experiment has shown that the state of artificially-induced stress inside reinforcements led the masonry panel to resist the stresses such as flexure and traction. In this way the pre-stressed masonry has a typical behaviour of elastic materials, such as structural steel and reinforced concrete. This procedure allows you to realize structures without the typical constraints of the traditional masonry linked to a structural function of box-type [5] and to create new architecture stone with organic forms, more free in the space than in the past. Moreover, thanks to the use of dry-assembled stone, the structure can be disassembled and both the armature and the blocks can be reused.

1.3 Double curvature vaults

To achieve the objective consisting in the design of temporary structures, we investigated the field of resistant structures for shape. For example, Mutsuro Sasaki realizes especially large and complex designs. He has developed specific expertise in structural optimization of reinforced concrete shells with free shapes and organic shapes, very complex from a geometrical point of view. The aim is to reduce, to a minimum, the size of a resistant element, eliminating the superfluous which does not collaborate with the structural purpose. The most recent examples, of this type of structures, can be found in the Crematory projected by Toyo Ito and in the Kitagata Community Centre by Isozaki. The studies of Sasaki refer to practical experiments on Gaudi's catenaries, or subsequent studies of Frei Otto on minimal surfaces not free in space, which are mathematically describable geometries [7].

In the field of structures resistant to form, from a static point of view, it is very interesting to observe that double curvature vaults have a greater ability to absorb – with only the efforts of the membrane – the external loads and have a considerable flexural rigidity in all directions, achieving a considerable bearing capacity, with equal free dimensions covered. Felix Candela and Eladio Dieste are both internationally-known for their sleek design of vaulted structures with a double curvature, respectively of reinforced concrete and brick's reinforced masonry. Candela culminated in his extraordinary capacity for understanding and managing complex geometries of the shells, in particular of the hyperbolic paraboloid. In the restaurant Los Manantiales in Mexico (Figure 3), there is a radial aggregation of 8 cloves of hyperbolic paraboloid along 8 parabolic diagonals. To cover large areas, with the use of reduced points of supports, Candela adopted a simple and economical structure that is made with the "inverted umbrella". In fact, the rectangular plane combines four sails, divided by straight lines that join at the centre in a single central column in which the exhaust pipe of rainwater is located.



Figure 3 Los Manantiales restaurant (Mexico) by F. Candela

Based on the technique of reinforced brick, that Eladio Dieste has developed, to realize large spaces, such as warehouses, factories, grain silos, supermarkets, bus stations and churches, there are two types of structures: the Gaussian vaults with double curvature and the self-supporting vaults. The reinforced brick technique allows for the use of small block sizes, is easy to move, and creates repetitive formworks that are removed after a few hours after casting and are reused for the next one, resulting in lower construction costs.

In the field of masonry shells experimentation, achievable without concrete reinforcements and without continuous formworks, Martin Speth retrieves the laying technique to build straight walls but according to morphologies and static behaviour of lightweight structures. With the aid of digital technologies to support the design and industrial production, Speth uses the prefabrication of arc segments with three-dimensional surface, easily assembled on site, in order to create a single large shell with double curvature (Figure 4) [8].



Figure 4 The masonry shell by Martin Speth

2 The stone shell

Research reported in the present paper has the objective to design a temporary structure that can be used as a uniform coverage for high-quality flexible open spaces for creative activities. This will be able to offer reversibility, recyclability for new uses, flexibility and aesthetic quality. To do this, research has deepened aspects that define: the entire constructive procedure of the structure through designing, the production of the constructive elements and the realization of the structure.

To define the entire constructive procedure of the structure, several issues have been deepened: morphological, technological, constructive, material, mechanical strength, production of the components, techniques for assembly and disassembly. Then, the defined constructive procedure of the structure will be verified through the realization of a prototype.

The considered previous experiences, on great coverage made up by Candela, Dieste and Speth, do not take into account two instances: temporary and sustainability. In fact, these double curvature vaults are not temporary structures, because they have been realized with constructive techniques that do not allow for disassembly. A temporary structure must ensure the full restoration of the prior conditions of the installation of the same structure, this is inextricably linked to the dry-assembled technique. Therefore, for this design, a construction technique that allows the creation of a structure that can be easily assembled and recycled for further use, must be considered.

In addition, the different used materials do not always have high durability in comparison with a material such as stone. In contrast, it is believed that several aspects that arise from previous experiences are very interesting and valuable in the design of the new structure. In fact, the idea takes its cue from the previous experiences conducted on the field of resistant structures for shape.

The peculiarity of the “inverted umbrella” is its double curvature surface, realized from straight lines according to two directions (x, y) with a hyperbolic paraboloid (hyper) shape. This allows to realize a coverage, characterized by this shape, in bearing masonry. By the use of reinforced masonry in brick blocks, Dieste has realized great and hardy coverage. Speth experiences, on prefabrication of masonry arc segments with three-dimensional surface, have facilitated the realization of great double curvature vaults.

The technological, constructive and material aspects of the structure have been studied taking into account previous investigation and experimentations yet started on the innovative use of ancient material of the building tradition as the natural stone.

Previous research, conducted on pre-stressed masonry in natural stone, has obtained excellent results that can be included in the present research. In fact, these dry-assembled masonries guarantee the complete removability of the structure. Moreover, the recycle of the components, mostly blocks in natural stone, is assured by the durability of the material that is able to withstand repeated assembly and disassembly. Capacity of the stone to resist compressive stress favours pre-stressing. It makes the masonry capable of withstanding tensile stresses induced by dynamic actions on structures. Therefore, pre-stressed masonry in natural stone, more than guarantee high durability, is dry assembled and it has mechanical performance comparable to those of elastic materials such as reinforced concrete.

Then research has investigated aspects related to mechanical resistance of the structure. All resistant elements have been dimensioned through modelling of mathematical calculation with the use of appropriate software.

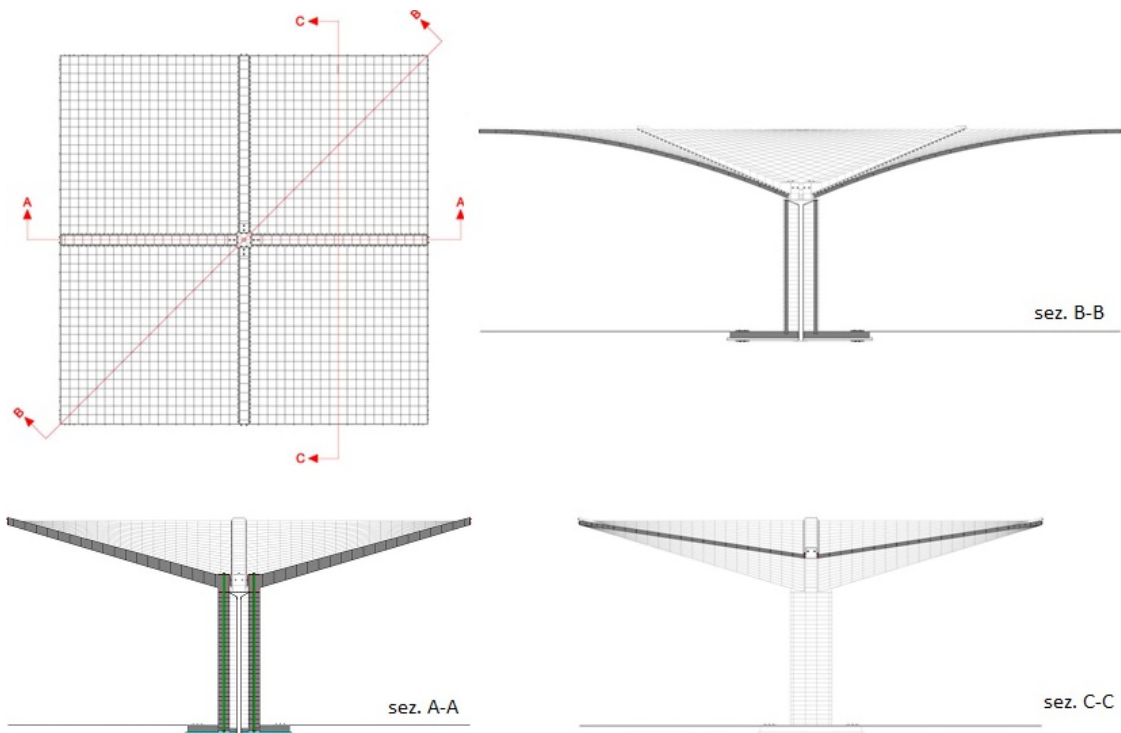


Figure 5 Plan and sections of the stone shell

In the end, the aspects related to: technologies and mounting assembly, prefabrication systems and industrialized systems for the realization of the elements of the structure have been studied, with the aid of digital technologies to support the design and industrial production.

The studied temporary structure in natural stone, which can be used as a uniform coverage for high quality flexible open spaces for creative activities (exhibition spaces, outdoor markets, refreshment areas) has a quadrangular shape of the plan dimensions 10x10m. It is composed by four hyper segments that are supported by four beams, placed along the centre-lines of the structure that discharge on a single central pillar (Figure 5).

The cover with a hyperbolic paraboloid (hypar) shape, based on Martin Speth's experience, retrieves the masonry technique but according to morphologies and static behaviour of lightweight structures.

It has been designed according to new constructive procedure of pre-stressed masonry with dry-assembled stone blocks. This allows you to realize a structure in natural stone that is able to resist static and dynamic actions, with small thickness, completely removable at the end of its use and recyclable for new use. The ground connection, too, has been designed so as to be completely removable.

The components that make up the structures are: the vault, the pilaster and the ground connection. The vault is composed by four hyper segments. According to the adopted constructive system, each of these can be individually seen as a "panel", simply joined to the beams by means of bolting. In turn, each segment has an axis of symmetry and is composed by 200 blocks of stone joined by a pre-stressed reinforcement [7-8]. This is located in grooves made in the blocks (for every 50 cm) in both directions. This reinforcement has a dual function:

- In areas subject to traction stresses, it makes up for the limits of the stone giving the structure an elastic behaviour
- It is able to absorb flexural stresses resulting from dynamic actions

The vault of the reinforcement is composed by strands in a sheath of polyvinyl chloride by Alga post (ϕ 15, 2 mm). The “panel” (Figure 6) is bordered by a steel plate (thickness of 1 cm) that acts as a contrast to the pre-stressed reinforcements. Moreover, it produces a confinement action of the vault. In the plate, in correspondence of the reinforcements, there are welded wedges, inclined like the vault, that allow a perfect distribution of the pre-stressing actions.

The block size is such as to obtain a continuous surface, both in the extrados and in the intrados. For this reason, the blocks have dimensions slightly different (around 25cm), keeping constant the height equal to 8 cm. The sizing of the blocks has been made to achieve the maximum level of series production in order to facilitate the procedure industrialized, through the use of integrated systems and numerical control machines. Because each segment of hypar has an axis of symmetry, there will be 90 blocks repeated 2 times and 20 single blocks with a total of 200. For the four “panels” of the structure, there will be a total of 800 blocks of which:

- 90 repeated 8 times
- 20 repeated 4 times

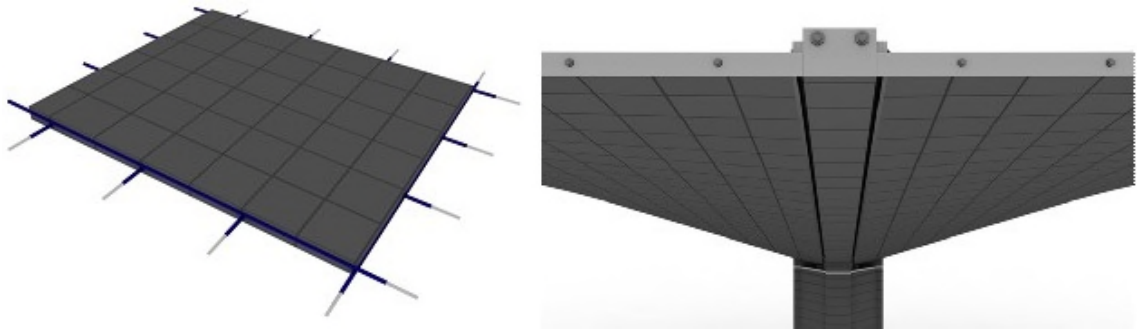


Figure 6 The panel

The beams transmit the load from the hypar segments to the pilaster (Figure 7). Each beam bears the weight of two halves of the neighbouring segments. It is composed by 20 blocks of stone with different height (25x30 cm in the joint and 25x16 cm at the extremity). The blocks have two holes (ϕ 3, 5 cm) where the pre-compression reinforcements are located. The rods are placed in the upper part of the blocks in order to absorb the stresses due to the bending moment more efficiently. The pre-stress is achieved by a post-impresed tension, in the aforementioned bars, and contrasted through two steel plates located at the ends of the beam. The connection between the panels and the beam is by means of pre-stressed bars, crossing the beam transversely. These bars are fixed to the plates of the confinement of the panels, through the nuts. Longitudinally, on both faces of the beam, a further plate (thickness 1.5 cm), allows you to leave a gap between the beam and the plate of confinement of the panel to accommodate the fixing nuts of the pre-stressed reinforcements of the panel.

The pilaster is constituted by the superimposition of 30 segments of the same size (Figure 10). The size of the pilaster, with hollow section, takes into account the flexure stresses, resulting from dynamic actions.

Moreover, the pilaster is crossed by a pipe for the disposal of rainwater. The blocks have a height of 10 cm so that are not excessively heavy during installation (about 60 Kg). Four holes, to allow the passage of the pre-stressed reinforcements, are present. The connection quoin (Figures 6-7) between the beam and the pilaster, has an additional hole where there is a post-tense steel rod (ϕ 32 mm) that links the pilaster both to the beam and to the foundation. At the top of the pilaster (Figures 8-9), a plate, welded to a galvanized steel funnel, is placed. This directs rainwater into the pipe (Triple-layer pipe with push-in connection Triplus by Valsir) passing through a galvanized leaf-grate.

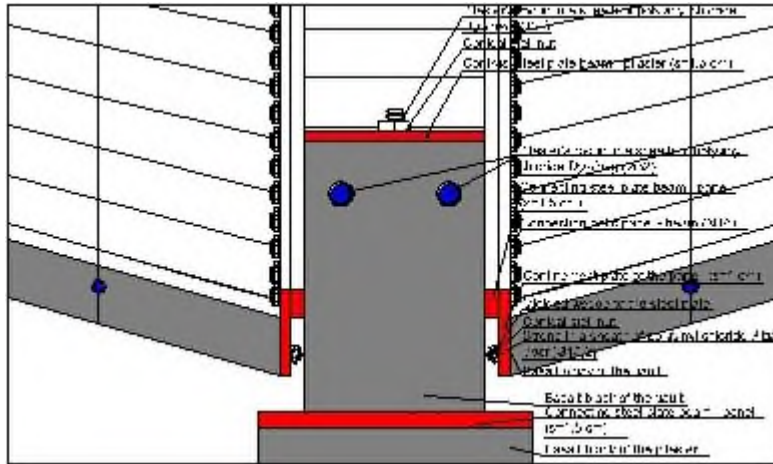


Figure 7 Detail of the node vault-beam-pilaster

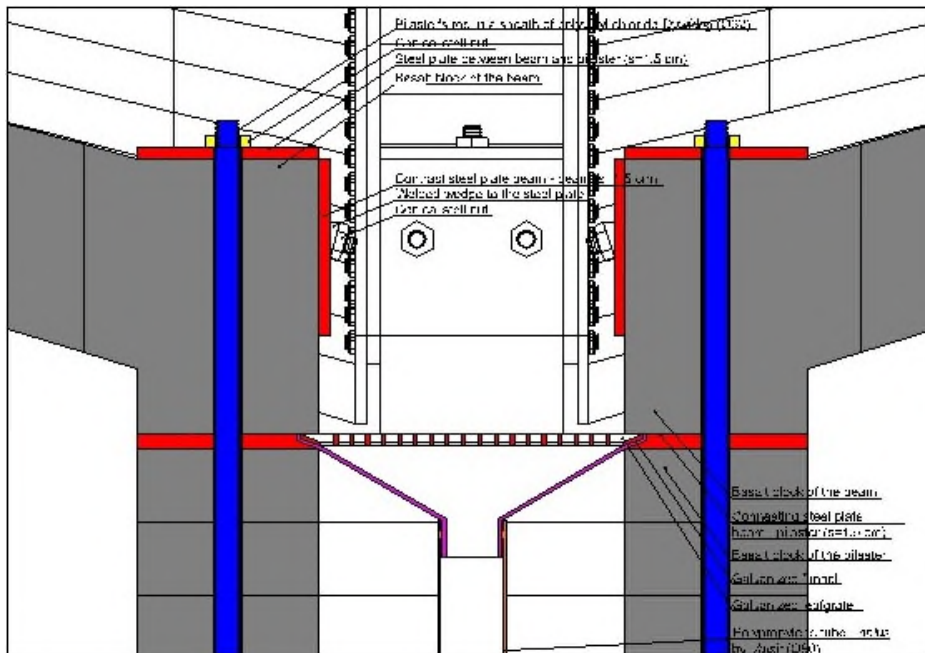


Figure 8 Detail of the node pilaster-beam and detail of the pilaster

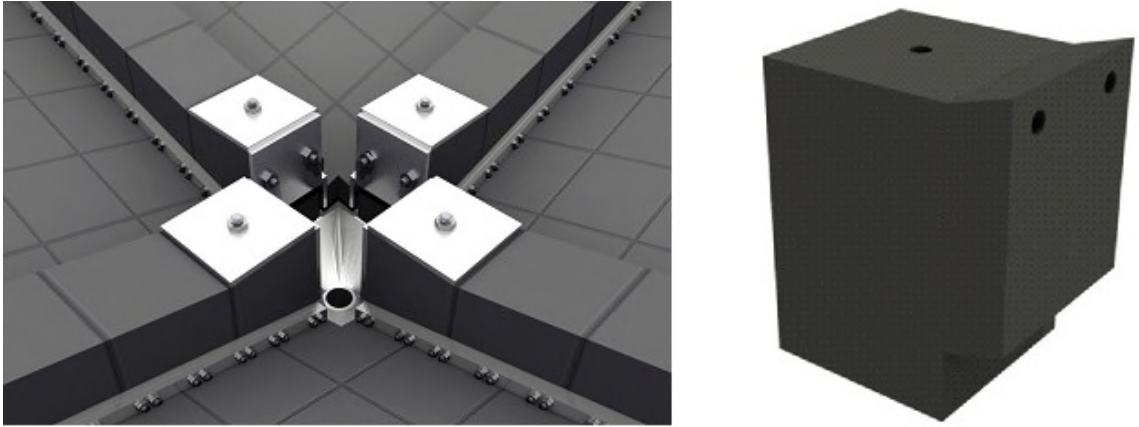


Figure 9 Detail of the central node and quoin

The ground connection (Figures 10 and 11) depends on the type of localization and morphology of the site. A minimally invasive ground connection could be constituted by a stone plinth (225x225x15 cm). The plinth is characterized by:

- A central hole (ϕ 130 mm) through which the rainwater pipe passes (Figure 10)
- 1 groove on the upper face (height of 5 cm) which acts as accommodation for the first block of pilaster (Figure 10)
- 4 grooves, on the lower face (height of 4 cm), to place the steel plate (2 cm) and the contrast nuts of the pilaster's reinforcements (Figure 11)

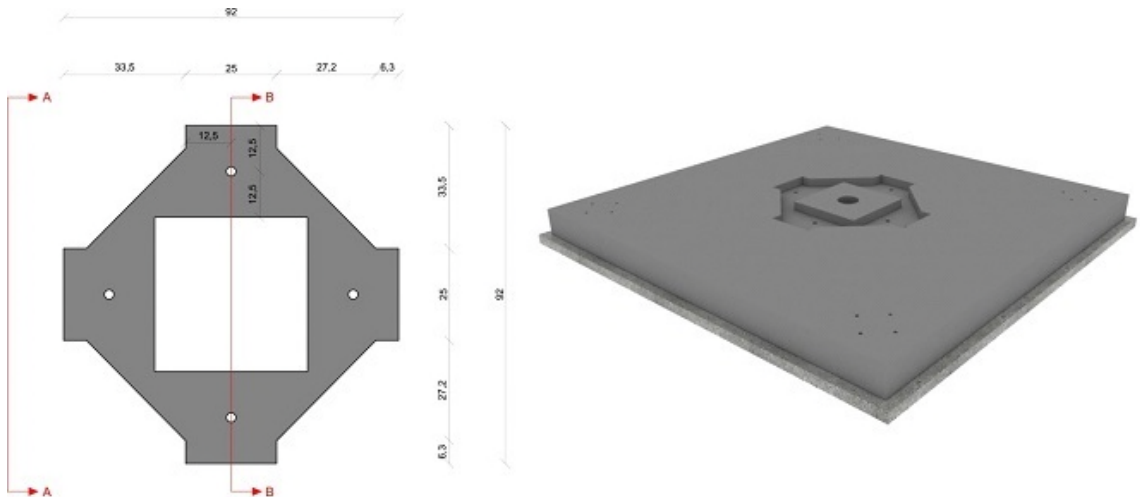


Figure 10 Blocks of the pilaster and of the foundation

At the corners there are four holes for the housing of the adjustable feet that allow a maximum setting of 60 mm, allowing a levelling of the plinth where the soil is slightly steeper. If the structure is realized in terrains with low bearing capacity or in the case in which this capacity is to recover in considerable depth, micro steel piles, driven into the ground and anchored by bolting to the stone plinth, can be used.

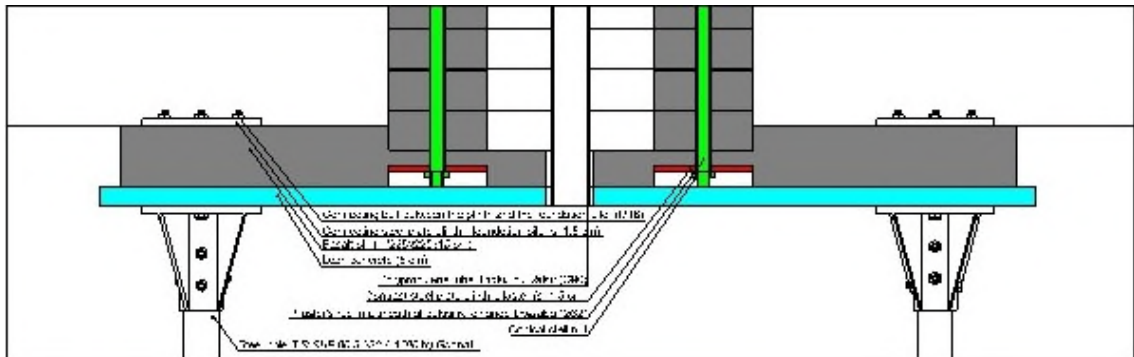


Figure 11 Detail of the node plinth-pilaster

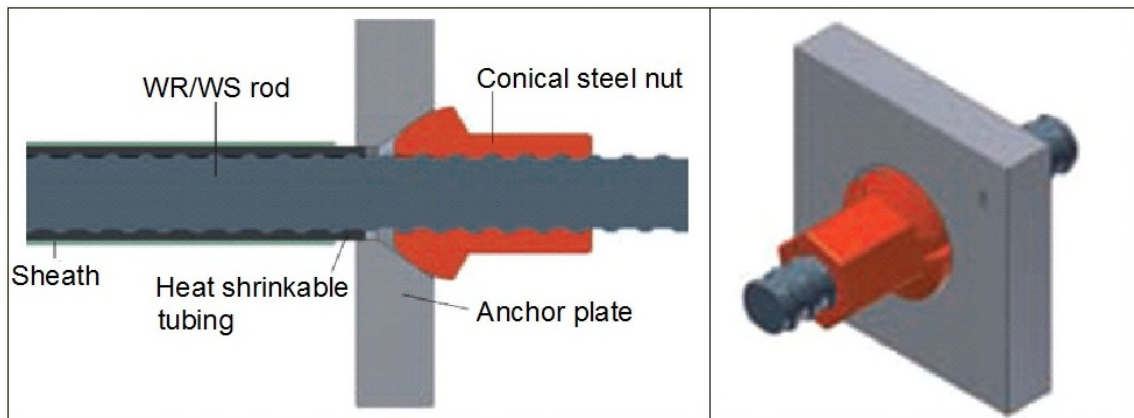


Figure 12 Detail of the node bar-plate

Reinforcing bars are degreased and coated by a polyethylene sheath. The fat that covers the bars within the sheath ensures adequate protection against aggressive agents and the smoothness of the cable (Figure 12). The anchorage is a fixed type, and it is located externally to the structural section of the stone: the cable is fixed to the plate through a conical nut. Being straight bars, the stringing is done just on one side. So, the pre-stressing of the panel is carried out on the external side. While, in the internal side that is bolted to the beam, the conical nut contrasts the pre-stressing action.

As already said, the stringing phases are carried out with the use of hydraulic jacks located in the stem and screwed on the ledge of the bar with a special sleeve. The technique of "pre-stressed sliding cables" or adopted post-tensioning, allows you, at any time, to release and collect the cables for some replacement. This also allows you to quickly be able to disassemble the whole structure with the full recovery of all used components, with the possibility to be rebuilt elsewhere.

2.1 Assembly procedure

Single components of the structure have been designed as to ensure a quick and easy installation of the structure. In fact, the dry assembly procedure reduces the processing time because timing of maturation of the mortar is not expected.

Depending on the extent of the area to be covered and so by the number of repetitions of a component, the realization of the shell may follow different assembly procedures. For projects of great extension, which provide a certain repetition of the structure, the four hyper segments of the shell, composed by 200 blocks of stone joined by a pre-stressed reinforcement can be prefabricated and partially assembled off site, according to the transportation needs. Then, at the work, the pre-assembled components will be placed above the pilaster by use of a crane. For projects of small extent, the shell can be made directly on the pillar through the use of ribs and scaffoldings.

The assembly procedure (Figure 13) of the pilaster involves the following steps:

- place the plinth and adjust the feet in order to level the upper face of the plinth position the exhaust pipe into the plinth, into the four circular holes of the plinth to place the steel cable and their sockets
- place the bottom plates and then tighten the sockets slide the pipe between the central holes of the segments
- place the segments in their exact position, at the end of the column to place the quoin head, paste the exhaust pipe with the walls of segments using a silicone waterproofing
- place the upper plate and tighten the socket with a torque wrench to give the required pre-stressing

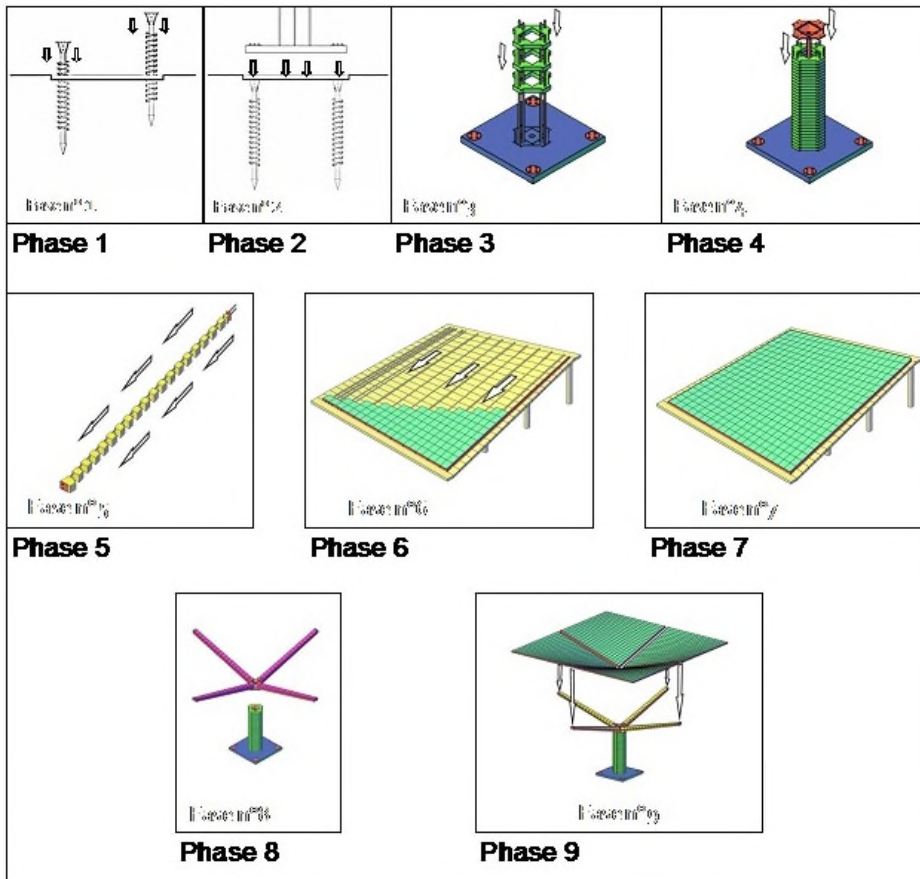


Figure 13 Assembly procedure

The assembly procedure of the panels involves the following steps:

- 1 realization of beams and application of stringing the bars by means of hydraulic jack
- 2 laying of the first angle plate and fixing of reinforcement for its contrast
- 3 pigeonholing of blocks of stone, taking care to place them in the right order
- 4 laying of the second plate and application of stringing the strands by means of hydraulic jack
- 5 Connection of the panels to the beams by bolts
- 6 Connection of the beams at the pilaster by the quoin head
- 7 Tensioning the metal plates of the pillar with a torque wrench

2.2 The shell structural testing

The hyperbolic paraboloid is a quadric whose medium surface has equation

$$z = hxy/ab \tag{1}$$

with:

h: deformation in the generic point P

a,b: dimensions, in plant, of the panel

Every vertical section is a parable or a straight line, while every horizontal section is a hyperbole or a couple of sloped straight lines compared to the x and y axes. Moreover, two straight lines of the same system are always oblique, while two straight lines of the different systems are always incidents and coplanar. Therefore, the hyperbolic paraboloid is a rifled quadric, in fact it has two systems of real straight lines such that, for every point on the surface, a line of the 1st and of the 2nd system passes.

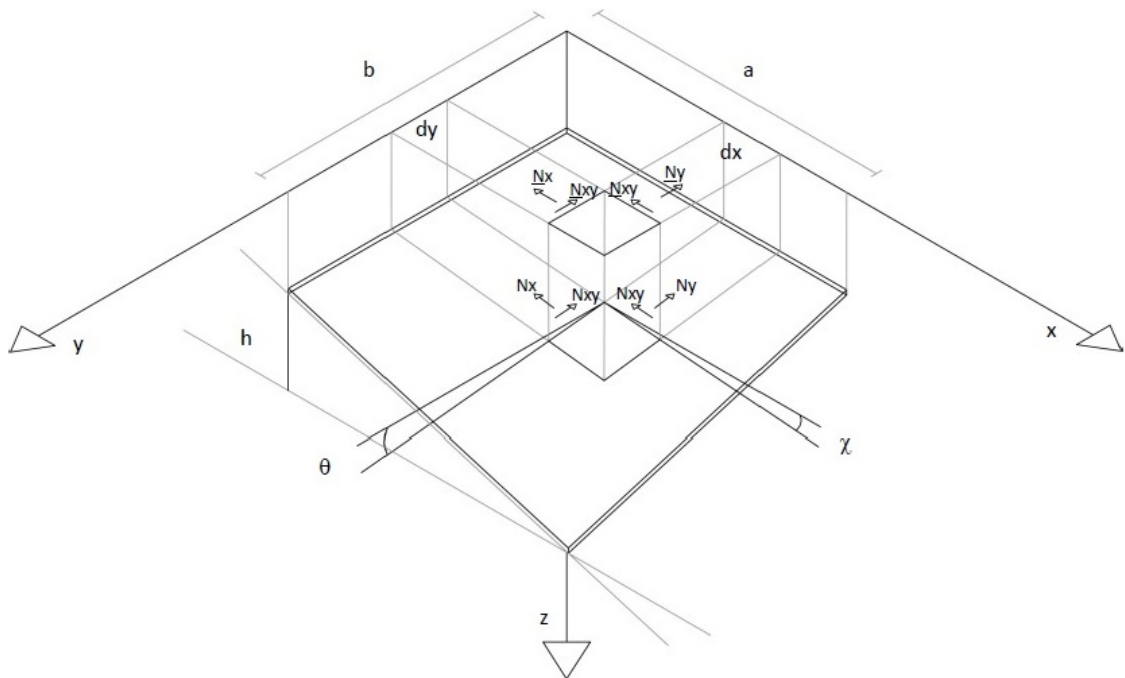


Figure 14 The hyperbolic paraboloid in the orthogonal Cartesian reference

In the case of the hyperbolic paraboloid with straight edges, the intersections of the surface with the vertical planes ($x=\text{const}$ e $y=\text{const}$) are straight lines. These, generally, do not intersect as right angles as happens instead for their projections in the horizontal xy plane. So you represent the stress of the membrane through a system of oblique tensions. A vault element, which has as a projection the little element (sides dx and dy) is showed in Figure 14.

In the studied structure, subject to a uniform distributed load (p), the single panel of paraboloid is bonded with elements able to absorb only reactant efforts in their plane but unable to react to normal efforts in their lying posture. This means that in the vault there are only negative efforts (N_{xy}):

$$N_{xy} = -pab/2h \tag{2}$$

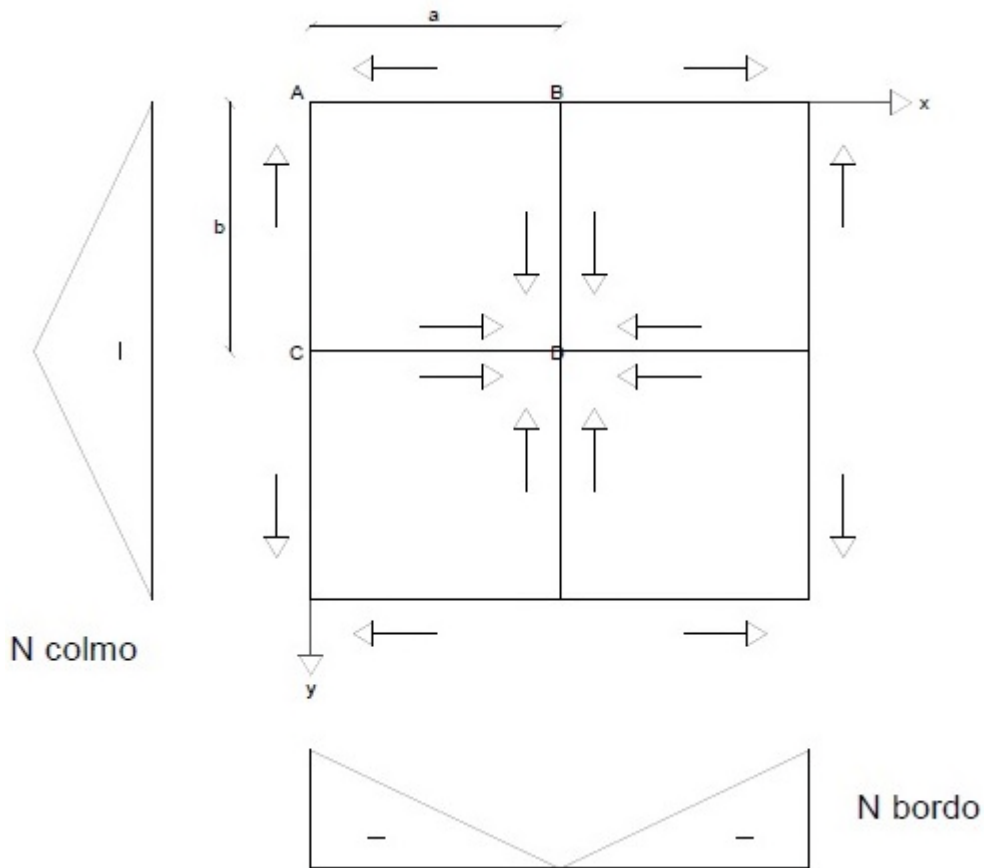


Figure 15 Compression forces in the vault

In correspondence to the board, a compressive effort acts due to the cutting stress. Its value is null in B and in C and it is maximum in A (Figure 15). The generic value is provided by:

$$N_{board} = \int_x a N_{xy} dx = \int_x a -pab/2h dx = -pab/2h * (a-x) \tag{3}$$

The generic value α of the normal effort at the top is provided by:

$$N_{top} = \int_0^x 2N_{xy} / \cos\alpha \, dx = -pab*x/h\cos\alpha \tag{4}$$

The structure has been analysed with the SAP2000 software through the finite elements method (FEM = Finite element method). The surface has been modelled by “thin shell” elements with a thickness of 8 cm, while the beams and the pilaster have been modelled by “frame” elements. The totality of the elements is composed by basalt blocks with density equal to 28, 5 KN/m³. The adopted sections are:

- Beam with a variable section (maximum section at the interlocking equal to 25x30 cm, minimum section at the end equal to 25x16 cm)
- Pillar with a hollow box section equal to 92x92 cm at the external side and thickness of 25 cm; central void equal to 42x42 cm

The following are the stresses acting on the little element of the vault. These are subjected to their load (Dead load case). The diagrams show: Smax (maximum traction efforts), Smin (maximum compression efforts), Fmax (maximum tensile stresses) and Fmin (maximum compression stresses).

Smax act within the volume of a generic element to withstand the application of the load (Figure 16). Smin arise from the integration of the stresses on the thickness of the element (Figure 17). It is very important to underline that Fmax and Fmin there are in every point of the median surface of the element (Figures 18 and 19).

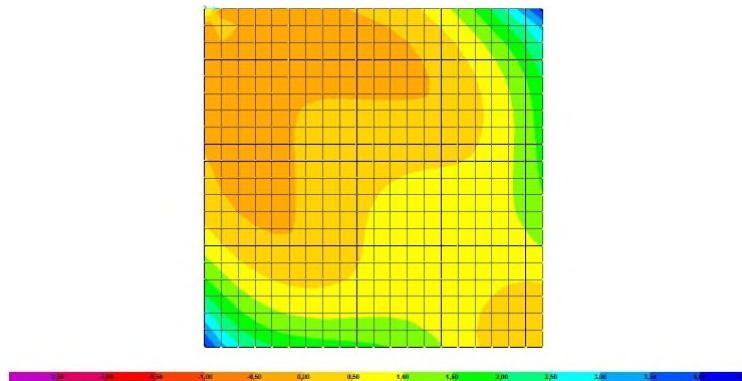


Figure 16 Smax diagram (MIN= -2524,0 KN/m², MAX= 4174,6 KN/m²)

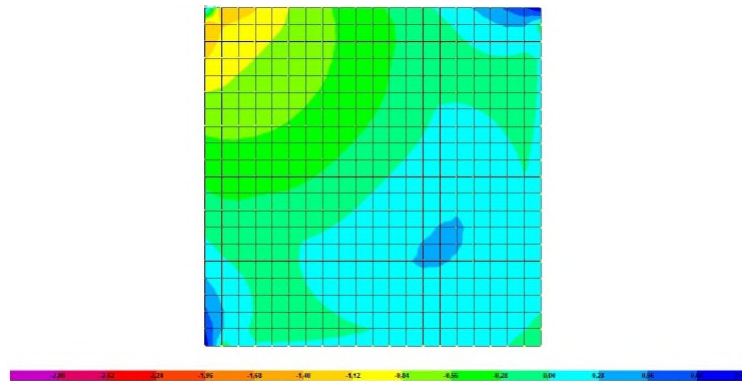


Figure 17 Smin diagram (MIN= -2804,8 KN/m², MAX= 1068,4 KN/m²)

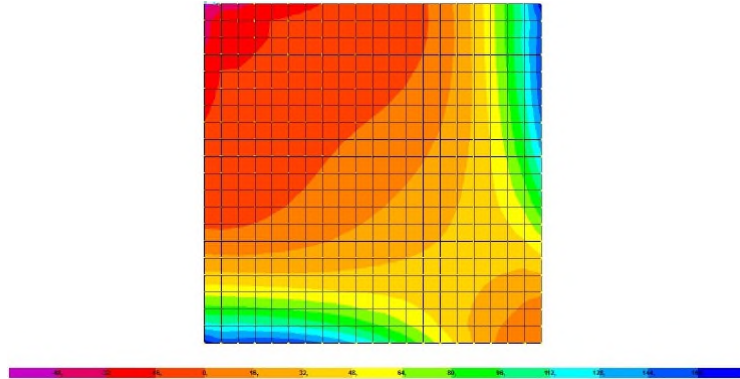


Figure 18 Fmax diagram (MIN= -54,6 KN/m, MAX= 168,6 KN/m)

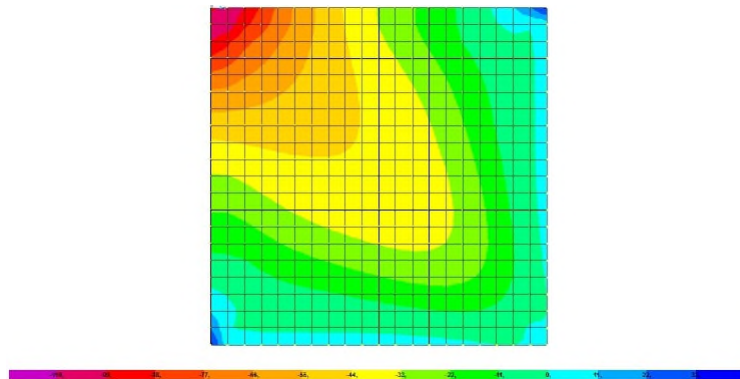


Figure 19 Fmin diagram (MIN= -114,0 KN/m, MAX= 36,4 KN/m)

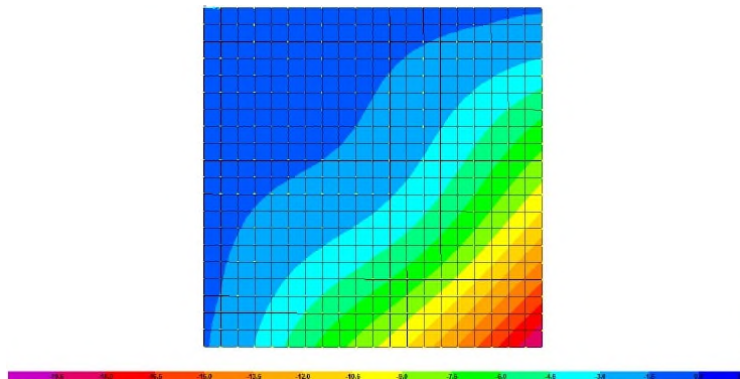


Figure 20 Diagram of the deformation (MAX= 19,9 mm)

It is possible to observe that the maximum compressive efforts are located in the central part, while the maximum traction is located along the board of the vault. In these areas, it will be necessary to utilize more pre-stressing reinforcement. In general, the vault is subjected to quite uniform efforts. Figure 20 shows the diagram of the deformation correspondent to the “Dead load case”. The maximum displacements, with a

value equal to 19,9 mm, are in correspondence to the edges.

The shell's elements are subject only to negative cutting stress. These generate, in some parts of the vault, traction stresses that are incompatible with the stone masonry panel. To overcome this, it is necessary to introduce reinforcements in those areas where there are traction stresses. To eliminate these stresses and to ensure the dry assembly of the blocks, a compression action is artificially imprinted to these reinforcements. Within the sections, this pre-stress has the aim to create a stress state that, added to that induced to external loads, reduces the effects.

As described before, the trend of the stresses on the vault produces isostatic lines of traction and compression inclined by 45° to the axis of the top. Based on this, pre-stressed reinforcements should be located along the isostatic lines of traction with value equal to $pa_b/2h$. From a constructive point of view, in the hyperbolic paraboloid with straight edges, it is more efficient to locate the reinforcements in the two orthogonal directions, along the lines where two successive rows of blocks intersect (Figure 21).

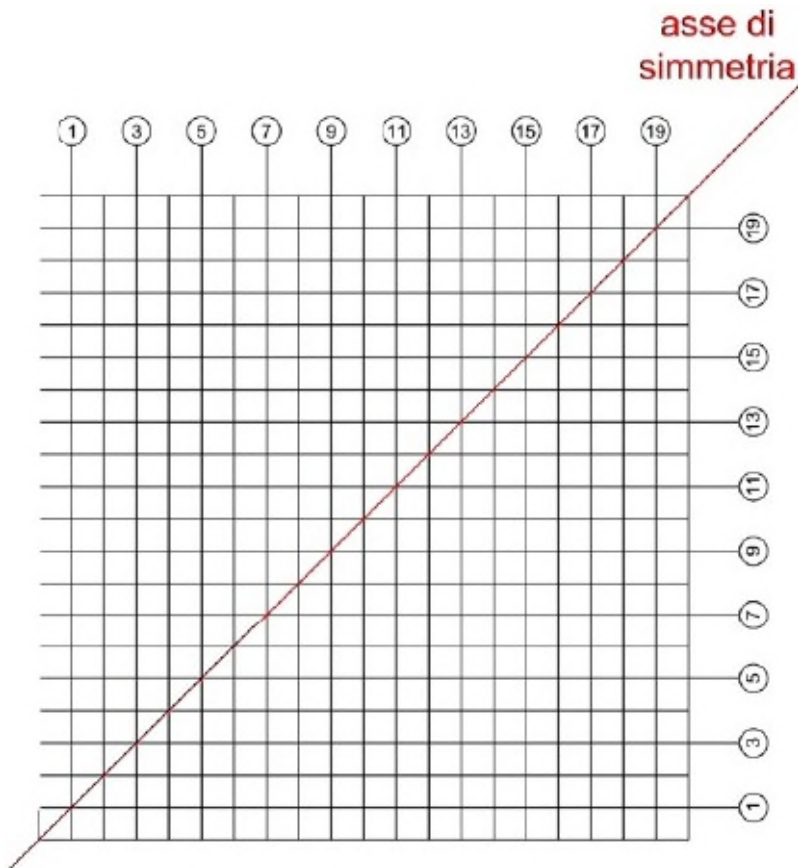


Figure 21 Vault's segment scheme indicating axis of symmetry and reinforcement placement

Pre-stressed reinforcements have a double function: they allow for the dry assembled of the blocks of the structure and they give the structure elastic qualities that allow it to absorb flexural stresses resulting from both external action (seismic and wind actions) as well as any minor construction defects.

Therefore, steel reinforcements are located, by the first block near the beam of the top, every 50 cm. This measure is equal to the width of two blocks. To determine the quantity of steel reinforcement, the vault surface has been modelled as a group of two-dimensional elements (shell thin), through the software SAP 2000. The resulting stresses have been added along the lines on which the reinforcement are arranged. Results obtained, equal in both directions because of the structure symmetry, are reported in Table 2. These values have been obtained taking into account of the amplification of loads through the legal ratios for calculating the ultimate limit state.

Based on the values of the normal efforts, reported in Table 2, it is possible to design the reinforcement in pre-stressing with the formula:

$$Aa.p. \geq N_{ed} / \sigma_{a.p} \quad (5)$$

with

$$\sigma_{a.p} = 0,9 f_{pk} / \gamma_s \quad (6)$$

It is possible to replace f_{pk} with the following values:

- $f_{p(0,1)k}$ (characteristic stress at 0.1% of residual unitary deformation, in case of threads or braids)
- $f_{p(1)k}$ (characteristic stress at 1% of total deformation, in case of strands)
- f_{yk} (characteristic yield strength, in case of bars)

The coefficient 0,9 is due to the hypothesis of a perfectly-elastic plastic behaviour of the steel in case of pre-stressing. While γ_s is the partial safety factor.

Table 2 Resulting stresses added along the lines on which the reinforcement are arranged

| 1 | 3 | 5 | 7 | 9 | 11 | 13 | 15 | 17 | 19 |
|-------|---------|--------|---------|---------|---------|---------|---------|---------|---------|
| KN | KN | KN | KN | KN | KN | KN | KN | KN | KN |
| +97.5 | +112.71 | +120.9 | +127.92 | +130.52 | +101.14 | +147.55 | +185.64 | +275.47 | +457.21 |

For the studied structure it is appropriate to utilize bars for the beams and the pillar, while strands will be used for the vault. Table 3 reports characteristics of the used reinforcement in the vault.

Based on these values, provided by the producers, the strands in a sheath of polyvinyl chloride Alga post will work as following:

$$\sigma_{a.p} = 1455,6 \text{ MPa} \quad (7)$$

Table 3 Characteristics of the used reinforcement in the vault

| Strands in a sheath of polyvinyl chloride Alga post | | | | | | | |
|---|-------|-------------------------------|--|---------------------------------|----------------|-------------------|--------------------|
| Diameter (mm) | name | Strands nominal diameter (mm) | Nominal diameter with sheath thickness 1.5 mm (mm) | Nominal area (mm ²) | f_{pk} (MPa) | $f_{p(1)k}$ (MPa) | Breaking load (KN) |
| 15 | T 15C | 15.2 | 18.7 | 165 | 1670 | 1860 | 307 |

Placing 3 strands T 15C (area equal to 495 mm²), with a pre-stressing of 160 KN on each strand, steel stress will be:

$$\sigma_{a.p} = P / A_p = 160 \text{ KN} / 165 \text{ mm}^2 = 969,7 \text{ MPa} \quad (8)$$

Based on NTC08, at the stringing moment, steel stresses must respect the most restrictive of the following limitations:

$$\sigma_{a.p} \leq \text{MIN} (0,85 f_{p(1)k}; 0,75 f_{ptk}) = 1252,5 \text{ MPa} \quad (9)$$

In this case, both limitations have been respected. Moreover, as for the concrete, it is possible to verify that, at the pre-stressing moment, in the basalt compressive stresses does not exceed the value:

$$\sigma_{\text{basalt}} \leq 0,70 f_{bk} \quad (10)$$

$$\sigma_{\text{basalt}} = P / A_{\text{plate}} = 160 \text{ KN} / (500 \times 80) \text{ mm}^2 = 12 \text{ MPa} < 0,70 \times 103 = 72,10 \text{ MPa} \quad (11)$$

This requirement has also been satisfied.

For line 19, at the end, 3 pre-stressed strands T 15C (each of 160 KN) will be placed for a total equal to – 480 KN. If line 17 is considered, it will be necessary:

$$A_{a.p} \geq 188,9 \text{ mm}^2 \quad (12)$$

So, 2 strands T 15S will be placed (area equal to 330 mm²) with a pre-stressing for each strand equal to 150KN, for a total of – 300 KN.

For all the others lines, just one strand will be necessary and checks required by the Regulations will certainly be fulfilled (Table 4).

Table 4 Reinforcement placed in each row and corresponding prestressed force

| 1 | 3 | 5 | 7 | 9 | 11 | 13 | 15 | 17 | 19 |
|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|
| 1 strand (T 15C) | 1 strand (T 15C) | 1 strand (T 15C) | 1 strand (T 15C) | 1 strand (T 15C) | 1 strand (T 15C) | 1 strand (T 15C) | 1 strand (T 15C) | 2 strand (T 15C) | 3 strand (T 15C) |
| KN | KN | KN | KN | KN | KN | KN | KN | KN | KN |
| -130 | -140 | -150 | -160 | -160 | -130 | -180 | -210 | -300 | -480 |

The wide margin of safety takes into account the layout of the reinforcement that is not widespread but discretized every two rows of blocks. It is necessary to consider that, even if the reinforcement is not widespread, the steel plate that borders the panel produces a confinement action of the vault, avoiding the outwards expulsion of the blocks.

As mentioned, beams are located along the intersection lines of the hyper segments (Figure 22).

Based on the fact that the vault's load is transferred to the beams and then to the pillar, it is assumed that each beam carries the load of two half of segment (quite 25 m²).

Considering the triangular load on the beam and its own weight, increased by the amplification coefficient of the loads for the calculation at the ultimate limit state, a total moment at the node is obtained equal to – 273 KNm.

With this value for the bending moment, ignoring the normal effort on the beam, it is possible to design the reinforcement of pre-stress through the formula:

$$A_{a.p} \geq M_{ed} / (0,9 d \sigma_{a.p}) \quad (13)$$

with

$d = 0,25$ m is the height of the section (distance from the compress board)

$\sigma_{a.p.} = 0,9 f_{ptk}/\gamma_s$ is yield strength stress of the bars

The used reinforcement is a Dywidag bar. Its characteristics are reported in Table 5. From this you obtain

$$\sigma_{a.p.} = 821,7 \text{ MPa and } A_{a.p.} \geq 1475 \text{ mm}^2 \quad (14)$$

with

2 bars 32 WR (area equal to 1608 mm²) and a pre-stress equal to 500KN for each bar, steel stress will be:

$$\sigma_{a.p.} = P / A_p = 500 \text{ KN} / 804 \text{ mm}^2 = 621 \text{ MPa} \quad (15)$$

Based on NTC08, at the stringing moment, steel stresses must respect the most restrictive of the following limitations:

$$\sigma_{a.p.} \leq \text{MIN} (0,85 f_{yk}; 0,75 f_{ptk}) = 785,5 \text{ MPa} \quad (16)$$

In this case, both limitations have been respected.

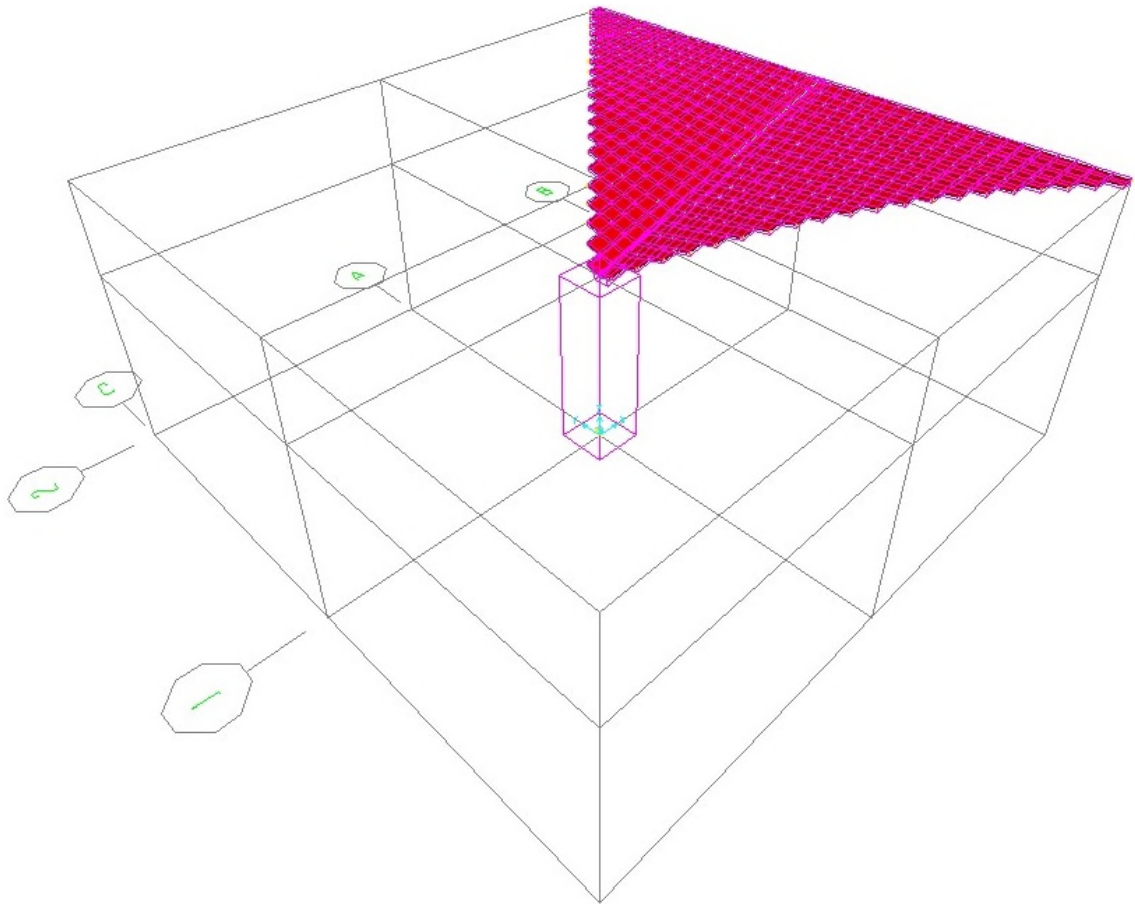


Figure 22 Reference model for the calculation of the bending moment on the beam

Table 5 Characteristics of the Dywidag bar

| Bar in a sheath of polyvinyl chloride Dywidag | | | | | | | |
|---|------|-------------------------------|--|---------------------------------|-----------------------|--------------------------|--------------------|
| Diameter (mm) | name | Strands nominal diameter (mm) | Nominal diameter with sheath thickness 1.5 mm (mm) | Nominal area (mm ²) | f _{pk} (MPa) | f _{p(l)k} (MPa) | Breaking load (KN) |
| 32 | 32WR | 32 | 35.5 | 804 | 950 | 1050 | 845 |

Moreover, as for the concrete, it is possible to verify that, at the pre-stressing moment, in the basalt compressive stresses does not exceed the value:

$$\sigma_{\text{basalt}} \leq 0,70 f_{bk} \quad (17)$$

with $f_{bk} = 103 \text{ MPa}$ that is the compressive characteristic stress of the basalt.

This requirement has also been satisfied because basalt stress is not superior to 25 MPa.

3 Conclusions

The studied structure is designed to be a viable solution to today's demand for temporary structures for "high quality" and flexible spaces. This structure, adaptable to the most varied demands (exhibition spaces, outdoor markets, refreshment areas), is modular, able to cover large areas with a reduced use of supports, easily disassembled and reassembled for other purposes. To do this, materials and techniques, that are typical of the heavy traditional construction such as stone masonry, have been used according to the typical instances of temporary structures, like lightness and removability.

The prerequisites, for the design of the proposed temporary structure, are based on the study of: proportions, geometric shapes, high strength materials, technologies and mounting assembly, modelling of mathematical calculation with the use of appropriate software, prefabrication systems and industrialized systems. The structure, defined by a large coverage, is inscribed in a square of 10 m and supported by a central pillar.

The proportion and geometric shape of the large coverage consist of 4 segments of hyperbolic hyperboloid. In these segments, belonging to the double curvature surfaces, structure stresses are mainly compression. The occurrence of flexural stresses, due to dynamic actions has been answered in the use of pre-stressed stone masonry.

The high compression strength of the stone allows you the use of pre-stressed stone masonry. Pre-stressed masonry panels, even with small thickness, are suitable to absorb also flexural stresses and therefore traction stresses, due to dynamic actions. This is thanks to the pre-stressing technique done with steel reinforcements adequately located between the blocks.

The use of pre-stressed stone masonry has made it possible to realize the temporary structure with a very thin stone shell and then with a low weight. The pre-stress applied by steel reinforcements, as well as giving greater strength and a low weight to the structure, has allowed us to implement a dry assembly process between the blocks of the cover.

As mentioned, the dry assembly procedure reduces the processing time because the timing of maturation of the mortar is not required. Moreover, disassembly allows us to recover all the structure's components. These could be reused in a new temporary structure, without be subject to change. This is a considerable economic advantage. In fact, the construction cost of the proposed structure, even if higher than the other temporary structures, is amortized by the different and repeated reuses that the structure could have over time.

The sustainability of the structure is favoured by the use of a material in itself sustainable, such as natural stone. The stone gives the designed structure a weight that although reduced, thanks to the pre-stressing, is definitely higher than that of a common temporary structure in lightweight materials. At the same time, the natural stone confers greater sustainability linked to its high durability due to the ability of the stone itself to age well and its propensity to recycling to be reused in other structures. In fact, thanks to the high durability, the natural stone is able to guarantee its aesthetic, mechanical and functional qualities in time.

A further simplification in the realization of the temporary structure, could be made with the aid of digital technologies to support the design and industrial production. Thanks to recent innovation in industrial production with the advent of CNC machines, allows you to easily make blocks with dimensions different from each other and the cuts with high precision and low tolerance.

The block size of the coverage is such as to obtain a continuous surface, both in the extrados and in the intrados. For this reason, the blocks have dimensions slightly different (around 25cm), keeping constant the height equal to 8 cm.

Because four segment of hypar, that make the coverage, have an axis of symmetry, there will be a total of 800 blocks of which:

- 90 repeated 8 times
- 20 repeated 4 times

Like Speth, who used the prefabrication of arc segments with three-dimensional surface, we easily assembled on site, in order to create a single large shell with double curvature.

Taking into account static and dynamic actions, for the structure designed in basalt stone with a surface area of 100 m², height of 3 m and a total weight at the base of about 28.000 kg, the structural checks have been largely tested. Reinforcements that verify the equilibrium conditions, for the shell made up of pre-stressed blocks of natural stone and thickness of 8cm, consist of a strand T 15C (area of 165 mm²) every 50cm, in both orthogonal directions along the lines where two successive rows of blocks intersect. Each strand is subjected to a pre-stressing of 150 KN which will double in the penultimate row and will triple in the last row of blocks corresponding to the outer edge of the vault, more subjected to traction stress. In the beams, two WR 32 bars, subjected to pre-stressing of 500 KN for each bar, are arranged.

3.1 Implications

We have tried to design a high flexible structure so as to be attractive and to be used by professionals to meet diversified needs and requirements of the architectural design. The structure can be used in several units in series as semi-permanent installation, reaching large indoor surfaces. The central vertical supports, approximately 10m away from each other in both directions, allow to realize great spaces without obstacles and suitable to accommodate large equipment or furniture. This favours the realization of great exhibition

spaces, outdoor markets and refreshment areas.

Or, as needed, the structure, can be individually used as a temporary installation by providing for the implementation of even one, two or three segments of hypar (Figure 23). These solutions can be applied if the surface to cover is of reduced extension (bus stops, entrances to underground, etc.). In all cases, the foundation plinth can be installed outside or below-ground in such a way as to allow the complete removability of the structure. Moreover, along the perimeter of the structure it is possible to insert a dry assembled vertical envelope to guarantee the thermal comfort. The vertical envelope could be: total or partial, opaque or transparent.



Figure 23 One, two or three segments of hypar

For the shape and the used materials, such as natural stone which can be local material, the structure establishes a positive dialogue with the contexts of different environments such as natural sites, also of some landscape interest, and towns also of historical interest. Figures 24 and 25 show two examples of the temporary structure with the stone shell designed with the local natural stone of the eastern Sicily: Etna basalt stone. This is the same local stone of historical buildings and monuments.

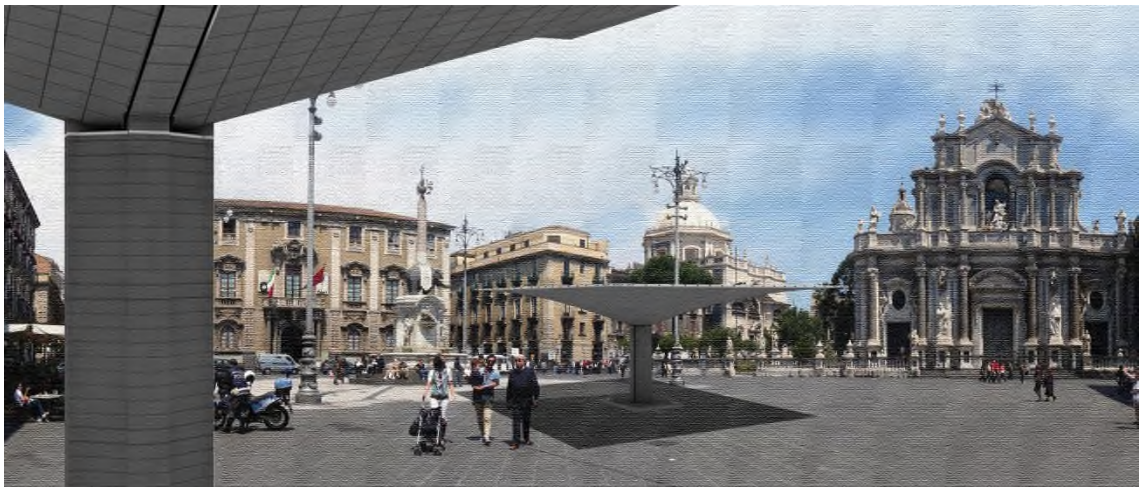


Figure 24 Render of the stone shell in Duomo Square, Catania

The removability of the structure is also favoured by simple operations of assembly and disassembly. In fact, skilled labour is not required and, excluding the foundation plinth, the heaviest element (the pilaster's block) has a weight that can be handled by two workers.



Figure 25 Render of the stone shell in Etna Park, Catania

Based on these considerations, the designed temporary structure, in the shape of an inverted umbrella realized in pre-stressed stone masonry, appears to be certainly competitive compared to what is available on the market, both from an economic point of view as well as for the positive impact for its originality, elegance and quality.

3.2 Future research

Results obtained by present research constitute a background of knowledge useful for the realization of a prototype. This will allow to verify the designing and executive procedure of the designed temporary structure.

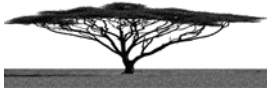
Moreover, research reported in this paper, through the designed temporary structure, shows as a material of the ancient constructive tradition has characteristics that make it contemporary and competitive if compared with other widely distributed constructive materials in architectural design. Pre-stress on the stone blocks radically modifies the structure behaviour, giving it mechanical performance similar to those of the elastic materials. This, as demonstrated in present research, greatly extends the use of pre-stressed masonry to different types of constructions, otherwise unfeasible in ordinary masonry, defining a new design process of sustainable and temporary constructions.

The temporary structure, studied in this paper, is part of a wider research aimed to the utilization of traditional materials, revisited with innovative techniques to exalt their performance. This study further aims to deepen the constructive technique made up by pre-stressed natural stone with the objective to define constructive elements to utilize both in infrastructure projects with low environmental impact, and in building construction with reduced energy use during construction, in the life cycle and at the end of life.

In light of new instances, laid down by dichotomy between innovation and sustainable development, the proposed constructive system arises with a global vision in the design process. This approach takes into account the technological progress in the stone working, without forgetting the specific characteristics of the site and the social context in which it has to operate. It proposes a revisiting of the architecture of stone, not being inspired by the simple principle of economy of the construction method that returns the strong identity of the masonry to the architecture of the new millennium.

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Towards a better, stronger and sustainable built environment

Aims and scope

Today's design strongly seeks ways to change itself into a more competitive and innovative discipline taking advantage of the emerging advanced technologies as well as evolution of design research disciplines with their profound effects on emerging design theories, methods and techniques. A number of reform programmes have been initiated by national governments, research institutes, universities and design practices. Although the objectives of different reform programmes show many more differences than commonalities, they all agree that the adoption of advanced information, communication and knowledge technologies is a key enabler for achieving the long-term objectives of these programmes and thus providing the basis for a better, stronger and sustainable future for all design disciplines. The term sustainability - in its environmental usage - refers to the conservation of the natural environment and resources for future generations. The application of sustainability refers to approaches such as Green Design, Sustainable Architecture etc. The concept of sustainability in design has evolved over many years. In the early years, the focus was mainly on how to deal with the issue of increasingly scarce resources and on how to reduce the design impact on the natural environment. It is now recognized that "sustainable" or "green" approaches should take into account the so-called triple bottom line of economic viability, social responsibility and environmental impact. In other words: the sustainable solutions need to be socially equitable, economically viable and environmentally sound.

IJDST promotes the advancement of information and communication technology and effective application of advanced technologies for all design disciplines related to the built environment including but not limited to architecture, building design, civil engineering, urban planning and industrial design. Based on these objectives the journal challenges design researchers and design professionals from all over the world to submit papers on how the application of advanced technologies (theories, methods, experiments and techniques) can address the long-term ambitions of the design disciplines in order to enhance its competitive qualities and to provide solutions for the increasing demand from society for more sustainable design products. In addition, IJDST challenges authors to submit research papers on the subject of green design. In this context "green design" is regarded as the application of sustainability in design by means of the advanced technologies (theories, methods, experiments and techniques), which focuses on the research, education and practice of design which is capable of using resources efficiently and effectively. The main objective of this approach is to develop new products and services for corporations and their clients in order to reduce their energy consumption.

The main goal of the *International Journal of Design Sciences and Technology* (IJDST) is to disseminate design knowledge. The design of new products drives to solve problems that their solutions are still partial and their tools and methods are rudimentary. Design is applied in extremely various fields and implies numerous agents during the entire process of elaboration and realisation. The International Journal of Design Sciences and Technology is a multidisciplinary forum dealing with all facets and fields of design. It endeavours to provide a framework with which to support debates on different social, economic, political, historical, pedagogical, philosophical, scientific and technological issues surrounding design and their implications for both professional and educational design environments. The focus is on both general as well as specific design issues, at the level of design ideas, experiments and applications. Besides examining the concepts and the questions raised by academic and professional communities, IJDST also addresses the concerns and approaches of different academic, industrial and professional design disciplines. IJDST seeks to follow the growth of the universe of design theories, methods and techniques in order to observe, to interpret and to contribute to design's dynamic and expanding sciences and technology. IJDST will examine

design in its broadest context. Papers are expected to clearly address design research, applications and methods. Conclusions need to be sufficiently supported by both evidence from existing research (reference to existing design research knowledge) as well as strong case-studies from any design discipline. A paper must contain at least one chapter on research questions, methodology of research and methods of analysis (the minimum length is 1500 words). The concluding chapter (the minimum length is 1000 words) will summarise the paper and its results. The concluding chapter also examines and discuss applications, advantage, shortcomings and implications of the investigation for both professional and educational design communities as well as for the people and the society. Also authors are also encouraged to include in this chapter a discussion of the possible future research that is required or is possible in order to enhance the research findings.

The papers considered for IJDST cover a wide range of research areas including but not limited to the following topics: Design research, design science, design thinking, design knowledge, design history, design taxonomy, design technology, design praxeology, design modelling, design metrology, design axiology, design philosophy, design epistemology, design pedagogy, design management, design policy, design politics, design sociology, design economics, design aesthetics, design semantics, design decision-making, design decisions, design evaluation, design sustainability, design logic, design ontology, design logistics, design syntaxis, design ethics, design objective, design responsibility, design environment, design awareness, design informatics, design organization, design communication, design intelligence, design evaluation, design education, design theories, design techniques, design methods, design operations, design processes, design products, design users, design participation, design innovation, design inspired by nature, design case studies, design experiments, etc.

The *International Journal of Design Sciences and Technology* is devoted to further exploration of all themes and issues that are directly or indirectly relevant to the exploration, introduction, discussion of design sciences and technology, cross referencing domains and any other themes emerging in the future.

Instructions for Authors and Review Process

Pre-review Stage (Editor Global Review): Papers can only be considered for review when they deal with a subject relevant to the content of the journal. In addition all papers submitted must follow the journal's paper structure and author instructions before they can be considered for review. These instructions also affect the content of the paper. The preferred size of a paper is about 10000 words (The minimum length of a paper is about 7000 words). The title must not be longer than seven words. Subtitles are not permitted. The maximum length of the abstract is 150 words. The paper must contain an introductory chapter with extensive literature review of similar research (the minimum length of the introduction chapter is about 1000 words). The paper devotes at least one chapter to detailed discussion of research questions, research analysis and research contributions (the minimum length of this chapter is about 1000 words). The conclusion will summarise the research and its results. In addition this chapter includes a detailed discussion of applications, advantage, shortcomings and implications of the investigation as well as future research for both design professionals and the design education (the minimum length of conclusions is about 1000 words). Submit a paper at this stage as PDF.

Review Stage (Peer Review): Only papers meeting all IJDST requirements can be considered for review. All papers are reviewed by at least two expert reviewers. The main author of a reviewed and accepted paper will be notified with instructions to resubmit the paper. All reviewed and accepted papers have to be resubmitted, implementing reviewers and editors comments and/or suggestions. Only accepted papers conforming to instructions should be considered for publication in the *International Journal of Design Sciences and Technology*. A paper should follow the IJDST paper structure. The review process will be repeated until all requirements are met.

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The paper will be written in the UK English. It will be single-spaced with 30 mm margins on all sides (paper size A4). Use Times New Roman for the main body of text (size 10), figures (size 8) or tables (size 8). The use of Bold, Italics, ALL CAPS, SMALL CAPS, etc. is discouraged. All chapters should be numbered consecutively (more than two level sub-headings is discouraged). All Figures and Tables with their respective captions should be numbered consecutively. They should each, be placed on a separate page, at the end of the paper. Give an approximate insertion point for figures and tables, between double square brackets. For instance: [[insert Figure 5]]. You will be asked to resubmit tables, figures and images if necessary. The paper must be submitted in plain text. Do not layout your paper. Do not use any styles or any automatic layout system. Please do not use 'Track Changes'.

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- [3] **Buxton, W** (1997) Living in Augmented Reality: Ubiquitous Media and Reflective Environments. In: Finne K, Sellen A and Wilber S eds, Video Mediated Communication, Erlbaum, Hillsdale NJ, 363-384
- [4] **Dixon, NM** (2000) Common Knowledge: How companies thrive by sharing what they know, Harvard Business School Press, Boston, MA

- [5] **Djenidi H, Ramdane-Cherif A, Tadj C and Levy N** (2004). Generic Pipelined Multi-Agents Architecture for Multimedia Multimodal Software Environment, *Journal of Object Technology*, 3:8, 147-169
- [6] **Gorard, S and Selwynn, N** (1999) Switching on to the learning society? Questioning the role of technology in widening participation in lifelong learning, *Journal of Education Policy*, 14:5, 523-534
- [7] **World Bank** (2002) Social assessment as a method for social analysis, World Bank Group [www.worldbank.org/gender/resources/assessment/samethod.htm]

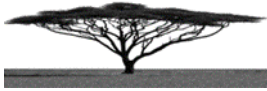
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