# MUSCLE-LIKE CERAMIC SKIN.
# A MATERIAL WITH LIGHT OF ITS OWN
# New Faculty of Psychology and Speech Therapy University of Málaga

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**System design team:**
**LLPS ARQUITECTOS S.L.P. (Design and work supervision). ITC, Instituto de Tecnología Cerámica (Design and testing). MAPEI SPAIN (Continuous grouting material). PROALSO (Tile installation). ACRATA (Manufacturing)**

**Client: UNIVERSITY OF MALAGA. SPAIN**

The University of Malaga's new Faculty of Psychology and Speech Therapy

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## 0. ABSTRACT

The New Faculty of Psychology and Speech Therapy on the University of Malaga's Teatinos Campus extension is an example of the significant capital outlays being made by the University to update and enhance its real estate.

**ARCHITECTURAL PROPOSAL, AN INHABITED FOREST:** The architects' proposal represents a different contextual concept, as it covers the entire plot of land earmarked for the project and provides a solution for this urban part of the Campus Extension. At the same time, the solution it proposes is radical in that it divides the project into two bodies: one a white and hermetic hanging ceramic that houses the teaching, research and staff areas, and the other, a vitreous, permeable body that reaches the ground and where all public functions at the Faculty will be held. In this manner, it creates the idea of a large architectural tree or forest where one can teach and learn amongst its branches.

**OUTER CLADDING, MUSCLE-LIKE CERAMIC SKIN**: The idea of the outer cladding for this forest is to emulate the leaves of a tree, which, when they move with the sun, capture different hues and nuances of light. This creates a potpourri of light and material sensations and images that range from the natural glazing to more metallic and even stony overtones at sunrise or twilight. Consequently, the entire ceramic system acquires the semblance of muscle contracting and dilating to maintain the whole building in balance, as if it were the skin of a snake. This entire universe of light was achieved through conscientious and highly-technological work in the factory and by testing its concave morphology and developing matt glazes in conjunction with the final geometry and grouting.

**INDUSTRIAL MODULAR DESIGN. APPLICATION AND EXPANSION**: The designers' obsession with innovation led to the idea of a continuous skin that would not change the apparent scale of the building's specific geometry, so it was imperative that it should not have visible joints but rather be unique when viewed as a whole, with no large items that needed to be anchored. The outcome was a small-sized (120 mm diameter), cylindrical ceramic of low thickness (10mm) which, once meshed to form 9-tile matrices, could be installed in a way compatible with the mesh glue and thus create a continuous, cement-based elastic grouting to join all the façade panels together as a single item. That way, it could be easily fitted to the façade's support structure to produce a unique and very special type of application.

A further challenge in the construction was to disguise the vertical expansion joints for the panels supporting the ceramic skin. To do so, a material of greater elasticity than the grouting was chosen that would adapt to the sinuous play of the circular tiles on the façade like a chameleon, and wind, in a strictly controlled manner, between the ceramic sheets and so become perfectly integrated with the whole.

**MANUFACTURE AND TESTING:** Starting with the quest for a ceramic piece that would serve such a unique purpose, followed by studies of the morphologies and innumerable geometric manipulations required to achieve the intended light effects, the colour and finish of the piece and its general grouting were finally decided. Numerous laboratory tests were carried out to determine dimensional characteristics and surface appearance, water absorption, breaking loads, thermal shock resistance, graze crazing resistance, chemical resistance, stain resistance, light fastness, and titanium dioxide's photocatalytic air-cleaning capabilities.

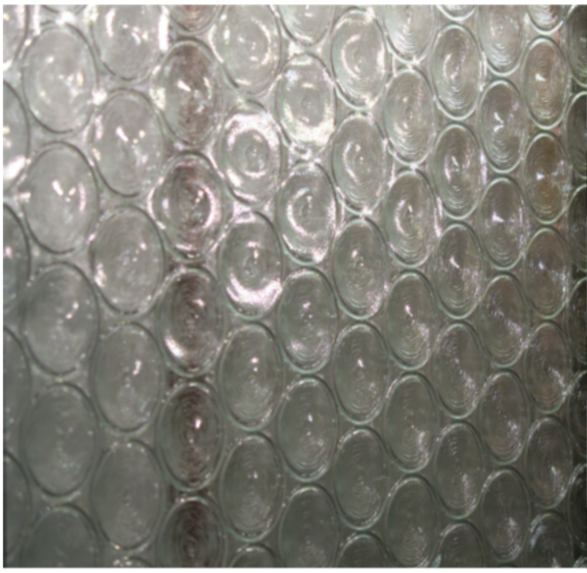
The closely co-ordinated, highly professional work carried out by the Project Management teams together with ITC, MAPEI, PROALSO, and ÁCRATA, from the outset of the project has brought to life a most singular building in regard to how it uses its ceramic skin in general and with a unique character as far as its construction at international level goes.

## 1. OUTER CLADDING. MATERIAL WITH LIGHT OF ITS OWN

### 1.1 INITIAL SELECTION OF MATERIAL

The idea of the outer cladding for this forest is to emulate the leaves on a set of trees that move with the sun to capture different tones and hues of light. Thus, it produces a veritable potpourri of light and material sensations and images that range from its natural glazed appearance to more metallic and even stony overtones at sunrise and twilight.

To achieve that, different research studies were carried out on various materials such as treated glass, varnished steel and glazed ceramics. The outcome of that research was a series of models and prototypes that led to the first two materials being discarded and the conclusion that ceramics was the most suitable material for the purpose. It meets requirements in terms of long service life, adaptation to curved geometries, and its controlled capture of sunlight and even of its own light. Investigations of the industrial market began in search of the best offers.



*Frosted glass prototype*

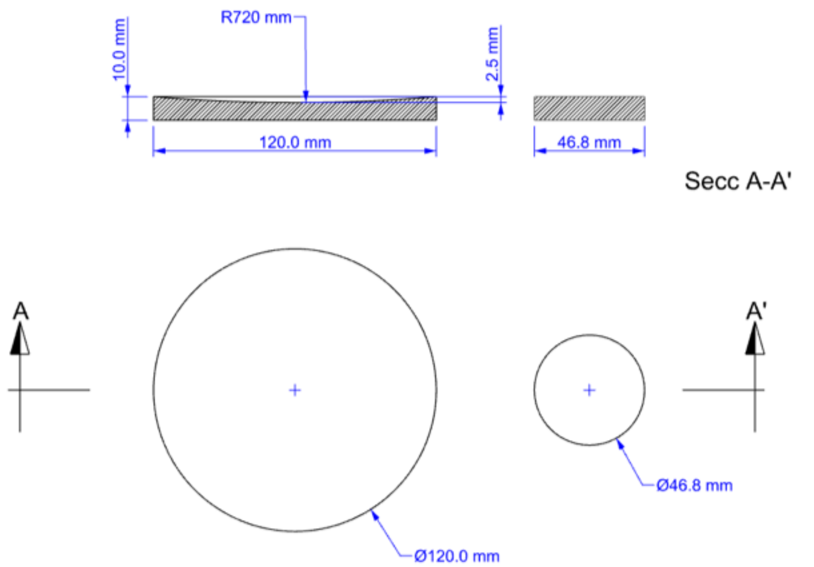
*Brushed treated steel prototype*

### 1.2. CERAMIC TILE SPECIFICATIONS

Once the material had been decided, the designers' obsession with innovation turned to achieving a continuous skin that would not make the building's special geometry appear to have a different scale because of the material. So, that material had to be of a small size and easy to handle to facilitate its manufacture, installation on the façade, and technical control. The entire covering had to have invisible joints and create a single image when viewed as a whole, and, to comply with the Building Code, it could have no large formats that had to be anchored (the size of the tiles had to be less than 300mm). Since the tiles were intended to clad an outer wall in an area of high sun exposure, a top-of-the-range white tile was chosen to minimise stresses from thermal expansion and to reduce the building's power consumption for air-conditioning.

## 2. IDEA AND DEVELOPMENT OF THE FINAL CERAMIC SYSTEM

After countless technical studies of the ceramic base piece's morphology, in which hexagonal, rhomboid and teardrop shapes were considered, it was decided to go for a low thickness (10mm), small-size (120mm in diameter) cylindrical tile. Such a tile adapts perfectly to the sinuous forms of the building and can accommodate the various small-scale window openings (60x60cm) between rows.




*Top and side views of the 120 mm and 46.8 mm ceramic pieces*

## 2.1. FINAL FINISH. MASS GLAZE vs GEOMETRY

The next step was to interpret what "material with light of its own" means: a material that, when exposed to any type of light, can reflect it, act as a diffuser or catalyst, and give that light a new direction, as if the light had emanated from within it. The actual biscuit of the ceramic material did not respond to the quest and for technical reasons concerning its all-weather behaviour, needed surface treatment. The surface glaze was the obvious technical point.

The idea came about of using a transparent mass glaze, about 2mm thick, that would give the outer surface a certain glassy appearance and could thus successfully fulfil the goal of a material with light of its own. To achieve that, the geometric hollow in the centre of the 12mm tile was used, as if each one were a bowl containing the glaze.

To that end, the section in the middle was hollowed a further 2mm to create a kind of spherical cap of mass transparent glaze that fades towards the outer perimeter.

To be able to apply the glaze on an industrial production line, it was necessary to adjust both the composition of the glaze, to prevent undesired colouring in the thickest parts, and the glaze-body fit, to avoid crazing during thermal shock tests. These adjustments had to be validated by testing cycles.

After several crazing and light fastness tests, a small fracture and slight yellowing in the centre of the tile was noted due to lead in the glaze composition. The glaze was not completely transparent either, so this option was discarded.

*Transparent mass glaze layer*

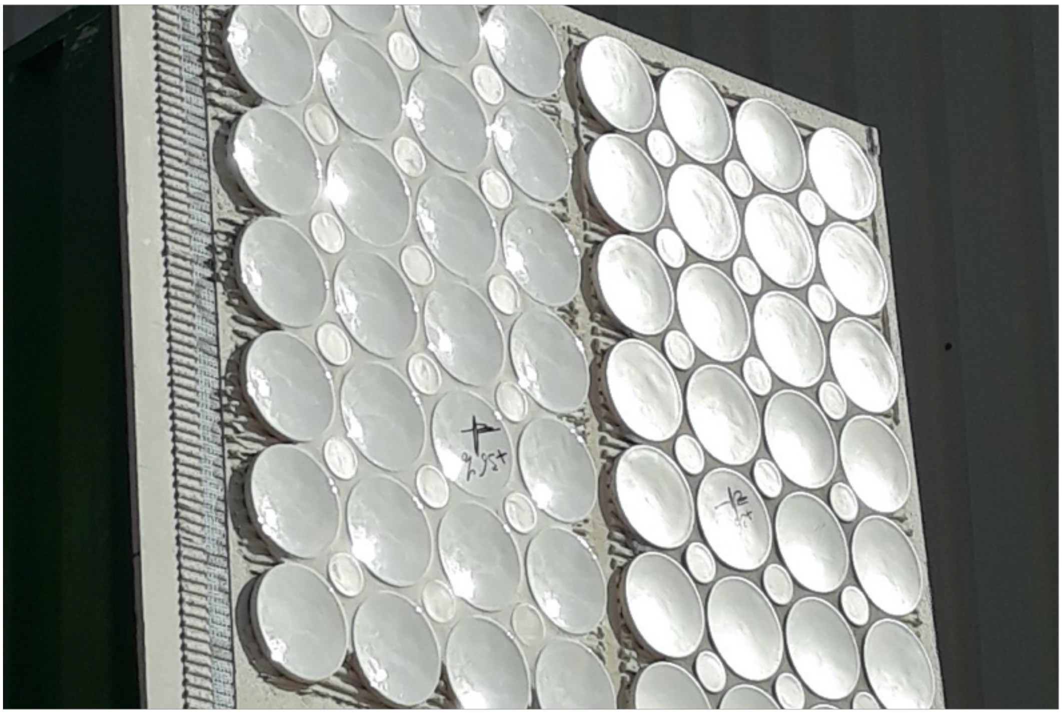
## 2.2. GLOSS GLAZE vs MATT GLAZE

During the process, it was noticed that pressing down the centre of the tile to increase the hollow area was producing different responses to sunlight on it and the result was further complicated by the choice between matt glaze or gloss glaze. Various prototypes and follow-up tests were carried out to achieve a successful outcome.

Gloss glaze produces an accurate reflection of what it is exposed to, thus producing an almost realistic mirror effect, full of spots from the exterior light which, depending on the time and angle of the light, made each tile too prominent, almost like an individual item, in complete opposition to the designers' intentions.

Matt glaze, on the other hand, captures all the exterior light on its surface and blurs it, thus creating a flake appearance that expels the light homogenously with the rest of the tiles in a harmonious and balanced fashion. Light appears to be emanating from the actual material. When its traditional finish was subjected to simple manipulation, this material became what we were looking for, where the geometrics take pride of place.

It is a clear example of how a profound understanding of geometry combined with the nature of things can transcend its own matter and properties.



*Prototypes showing contrasting sun exposure between gloss glaze (left) and matt glaze (right)*

## 2.3. TITANIUM DIOXIDE?

Additionally, given the constant and permanent concern with sustainability and environmental co-existence, the option of using materials, such as titanium dioxide, that are self-cleaning and decontaminating thanks to photocatalysis with sunlight, was studied and tested.

Using outer layers of titanium dioxide nanoparticle suspensions calls for an aqueous slip with a high content of titanium dioxide nanoparticle solids (average diameter: 20-40 nm) and with an anatase/rutile ratio of 3:1 (to obtain a photocatalytic surface, the titanium dioxide has to be in the form of nanoparticles and in the anatase crystalline phase).

The photocatalytic properties of the application were tested to ISO standard 22197-1. This test method is used to determine air purification performance by materials containing a photocatalyst or whose surface has a photocatalytic film. This part of the standard can be used for different solid building materials.

The test consists of exposing the sample to a constant flow of polluted air whose concentration is known and the specimen's performance is measured by evaluating the net amount of nitrogen oxide (NOx) removed.

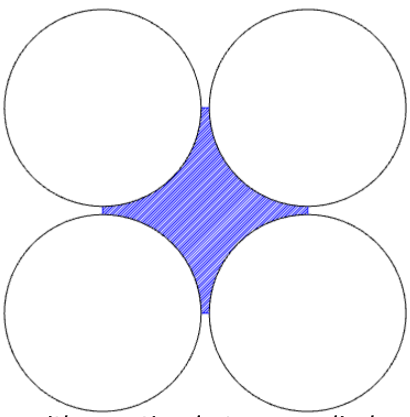
Finally, its use was ruled out because, after performing all the tests, the degradation on the matt glaze surface showed significant signs of ageing and its photocatalytic properties were minimal, even though it did comply with the test parameters.

## 2.4. FINAL SIZES AND GROUTING. PROTOTYPES

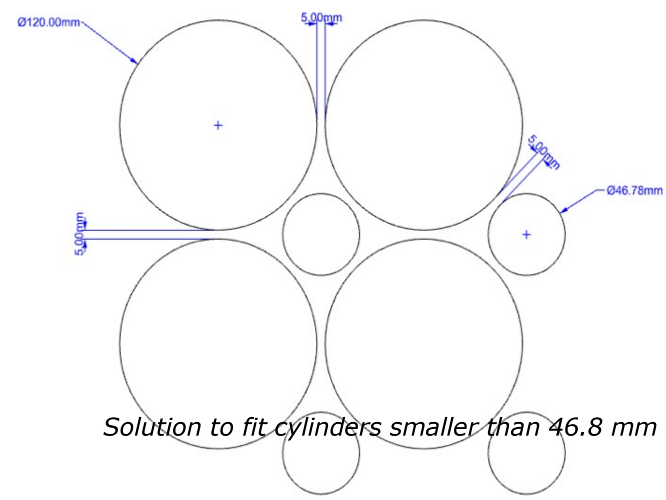
In view of the precise elevated layout of the open spaces inside the new Faculty, the decision was taken to install the tiles in a right-angle arrangement. That was to avoid any equilateral triangle arrangements that could produce strange or difficult areas to overcome in corners, changes of plane or gaps.

Furthermore, given the need to create clean surfaces with no joints or steps, it was decided to work out what expansion or movement joints were needed to divide the wall into surface areas of less than 25m$^2$ with a linear arrangement of maximum 6 metres, as required by all current regulations. The minimum width of those movement joints had to be 5mm. Therefore, by bringing together all the parameters and variables stated so far, it was decided that all the large façade panel should have one continuous expansion joint, i.e., the gap between all the ceramic tiles was to be 5 mm at the least. That way, any cracking of the facade could be avoided without jeopardising its overall scale.

As a result of that decision and of the orthogonal matrix arrangement, an issue arose with the accumulation of a large amount of grouting material in the gaps between the cylindrical tiles. This problem led to a study of different ceramic designs and prototypes to fill the gaps by recessing the area to create a ceramic tile with two depths and various edges. Finally, a proposal was made to fit a smaller ceramic tile in the gap between the cylinders and which was to be built into the tile installation system, yet to be decided, and which could even be fitted individually in places with difficult geometry or complex edges.

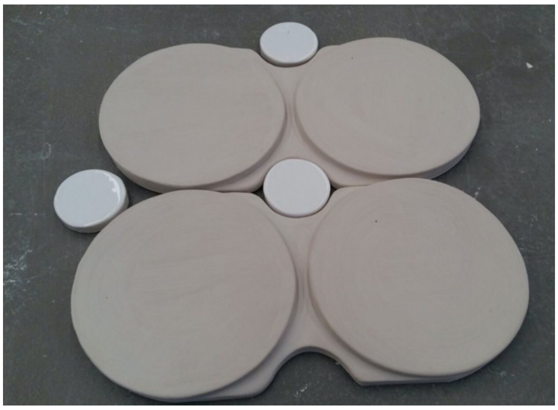


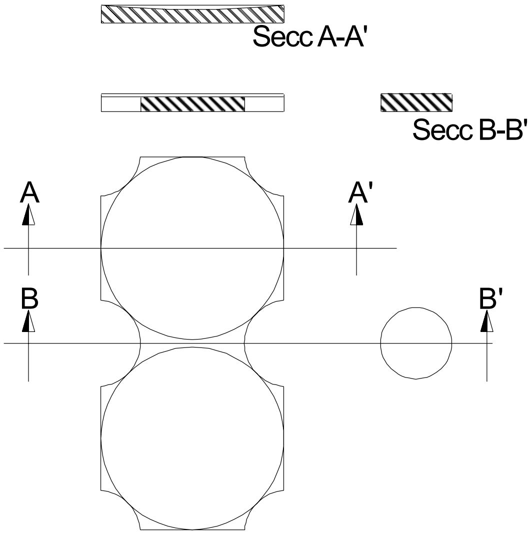
*Gap with grouting between cylinders.*



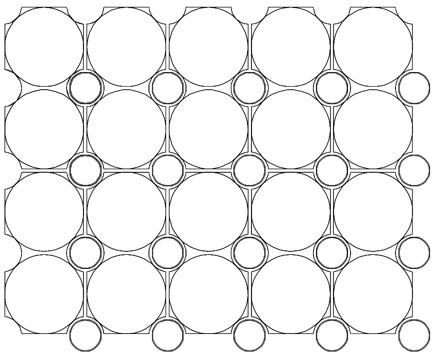

*Solution to fit cylinders smaller than 46.8 mm*

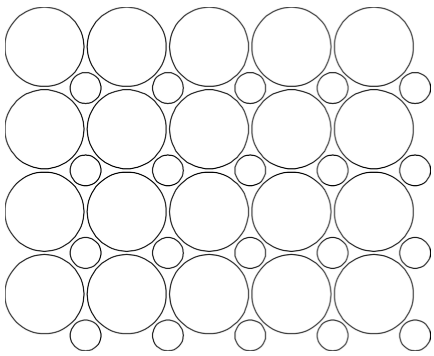
To make installation faster, the first proposal consisted of altering the initial formats in such a way that the cylinders were joined together in pairs, as shown in the photo below, and finally the grouting was used to provide the sought-after cementitious and homogeneous appearance, in contrast to the purity of the finish on the ceramic piece.






*Before applying the grouting* *After applying the grouting*





*Discarded prototype and design of the first complete system prototype with recessing for grouting*

In the end, it was decided to use separate cylindrical formats, since applying the grouting would present additional problems, as certain undesired visual effects and movements due to high sun and heat exposure could appear if grouting was applied at two different depths. The system arrangement finally chosen was the one comprising cylinders measuring 120 mm in diameter combined with other smaller ones of approximately 47 mm diameter, set on a mesh.

## 2.5. NATURE OF GROUTING MATERIAL

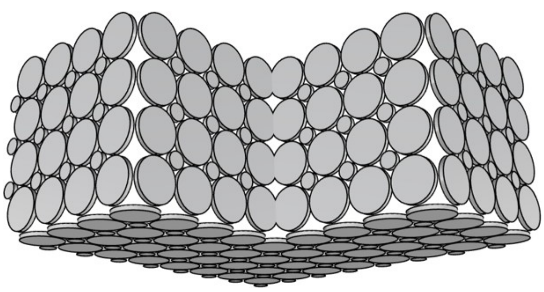
In view of tile geometry and in order to ensure the system worked properly, the next strategy involved resolving the question of expansion joints. Given the small size of the tiles, the proposal was to afford great elasticity to both the adhesive material and all the joints so that they could absorb any movement due to heat expansion. Such a solution would render constructing expansion joints as specified in UNE standard 138002 unnecessary. The **adhesion and grouting** recommendations specified by ITC for ceramic systems were applied.

To do so, a material was selected for joints measuring 5mm and greater in width. This highly elastic, polymer-modified grout paste, with a reach of up to 10mm, is water-repellent with DropEffect and mould-resistant with BloBlock technologies and most suitable for grouting ceramic tiles.

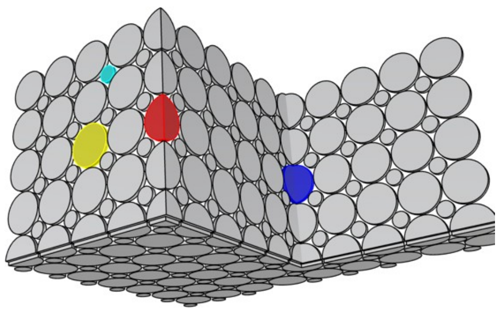
## 2.6. SOLUTION FOR SPECIAL CORNER TRIMS

This need arose because of the building's geometric complexity, with its large-scale panels, which, although all vertical, produce clearly angled edges and sinuous curves that start from a straight section and thereafter slide naturally, emulating a vertical sea wave.

To solve the problem of intersections on concave or convex edges, two different strategies were proposed. The first was to accurately calibrate whole tiles when planning the exploded arrangement of each wall, and then creating a live corner piece using grout and a reinforcement that would allow a clean edge to be formed in any direction. The second strategy was to produce three-dimensional ceramic pieces to fit individually on concave and convex corners. To do that, their format would have to be altered to match the exact intersection at the corner, i.e., a convex corner piece would be larger than a concave one, as the illustrations below show.



Strategy 1. Model with whole tiles in a live corner.



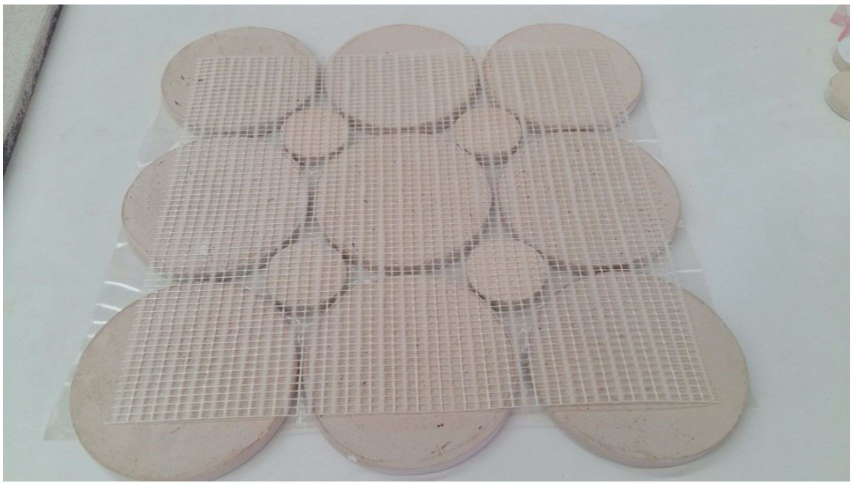
Strategy 2. Model with 3D concave and convex tiles

Finally, after thorough trials and tests, it was possible to overcome all intersections by applying Strategy 1, which greatly simplified the issue on all walls, that now appeared to be independent although visually continuous. All corners have a live edge reinforced with water-repellent elastic grout. Thus, the same construction system can be used for all the ceramic tiles in concave and convex corners.

## 3. TILE INSTALLATION, ADHESIVE, AND GROUTING TECHNIQUE

### 3.1 CERAMIC MATRIX MESHING

The proposal was made to mesh the tiles in modules of nine large cylindrical pieces and their corresponding nine smaller cylinders. The illustration below shows an example of the mesh used to facilitate tile installation.



*Mesh with 9 x 12mm and 4 x 46.8 mm pieces with special compatible adhesive*

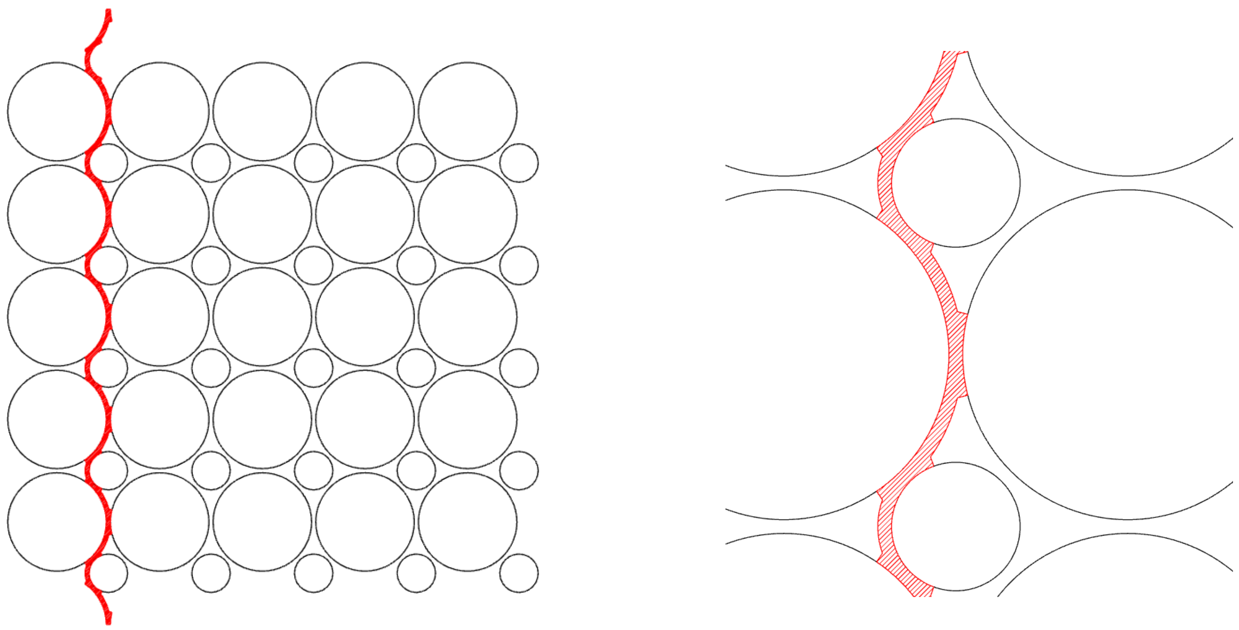
This mesh enables fast installation. However, to ensure the pieces were correctly spaced, a template negative of its shape can be used, made of rigid but nevertheless flexible aluminium or plastic. Finally, everything was calibrated manually to trace detailed vertical layout lines and the overall arrangement, with its nails and spacers, around the entire perimeter of the building.

## 3.2 GENERAL TILE INSTALLATION TECHNIQUE. STRUCTURAL JOINTS

The base substrate of the ceramic facade is made up of prefabricated cement panels covered with structural 1 cm expansion joints fitted along the entire perimeter of the façade every 14 metres approximately. This implies that the joint has to extend from the surface of the ceramic tile to the intersection with the base substrate's own joint, meaning that it is directly visible on the outer face.

This visibility of the base substrate was a challenge for the project because it meant making a series of vertical joints that split the building into several parts across the continuous array of cementitious grout and tiles. The scale of a single unit that had been so ferociously defended would be lost. The solution found was to make a joint which, although vertical, fluctuated with the ceramic tiles so that it could be built into the system like a chameleon. A neutral, mould-resistant silicone mastic for ceramic tiles was used, with Teflon tape to prevent it sticking to the bottom of the joint.

The installation technique for the ceramic tile system was to lay a thin coat of adhesive cement with a notched trowel. Taking the size and weight of the pieces into account, although they were on meshes, it was not considered necessary to use buttering and floating. The adhesive cement used was C2 ES2-rated, which is an improved cementitious adhesive with prolonged open time and high deformability.



*Design of the path of the structural expansion joint over the base substrate of the prefabricated cementitious system*

This solution meant that the overall appearance that had been sought from the outset was finally achieved.

The ceramics were then installed, levelling and making the layer of adhesive on the surface perfectly uniform using a 40 x 15 cm flattener. Vertical reference lines, nails and spacers used to ensure a perfect arrangement of all horizontal, vertical and diagonal lines.

Grouting was carried out under shaded scaffolding to protect it from direct sunlight and thus avoid accelerated setting of the various jointing and adhesive materials.

Finally, all material debris was removed and the panels cleaned with specific finishing tools.

All the roofing in outdoor areas was covered with the same material and the same tile installation system.

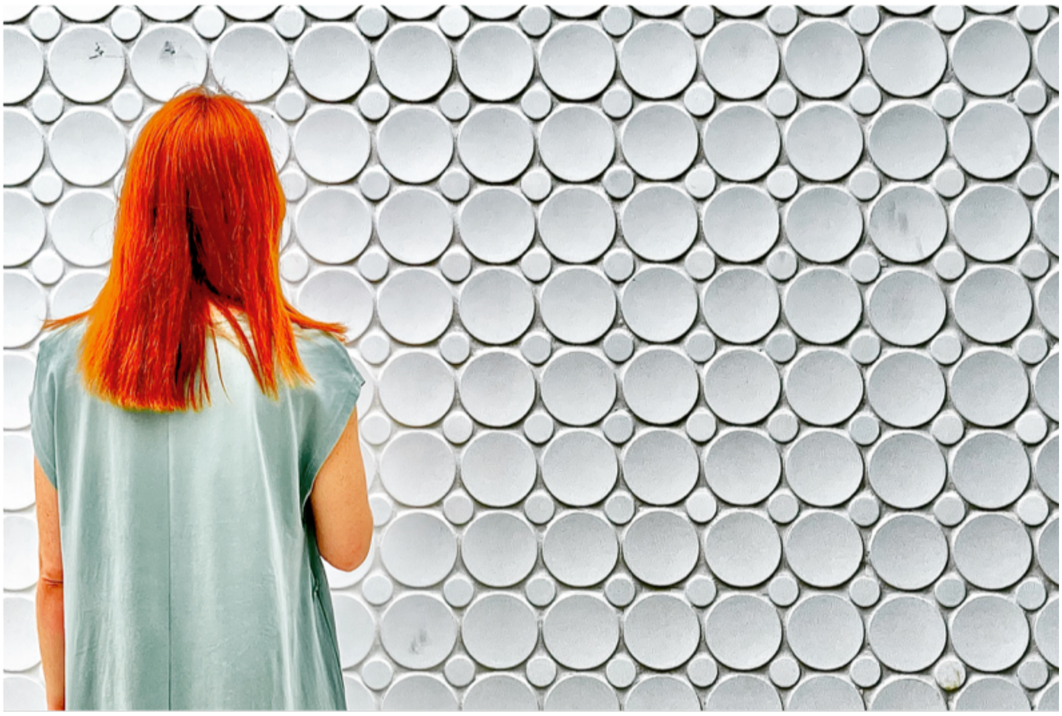
Consequently, with the prototype developed in collaboration with ITC, the ceramics as a whole look like a muscle contracting and dilating to maintain the balance of the building's entire body, as if it were the skin of a snake. This entire universe of light was achieved through conscientious and highly-technological work in the factory and by testing its concave morphology and developing matt glazes in conjunction with the final geometry and grouting.

Leading companies at international level played a part throughout the process in close collaboration with ITC and, without their support and know-how, this ambitious building project, the first of its kind in the world, would never have been possible.

| Characteristics | ISO 10545 | Results | ITC Report Specs for LLPS Architects | Evaluation |
|---|---|---|---|---|
| **Surface appearance**<br>Percentage of pieces with no defects | 2 | 100% | **100%** | Compliant |
| **Dimensional characteristics**<br>Maximum deviation | 2 | | | |
| On work sizes – diameter | | -0.08%. +0.34% / -0.1mm, +0.4mm | ±0.6% / ±2.0mm | Compliant |
| On work sizes - thickness | | -2.15%, +2.15%/ -0.2mm, +0.2mm | ±5% / ±0.5mm | Compliant |
| **Water absorption** | 3 | D=120mm: E=4.0%<br>D=47mm: E=5.4% | <3% | See **Note** |
| **Bending strength** | 4 | | | |
| Breaking load | | 2370 | >450N | Compliant |
| **Resistance to thermal shock** | 9 | Resistant | Resistant | Compliant |
| **Crazing resistance** | 11 | Resistant | Resistant | Compliant |
| **Crazing resistance**<br>**2nd cycle 5 bar x 2 h** | - | Resistant | Resistant | |
| **Crazing resistance**<br>**3rd cycle 5 bar x 2 h** | - | Resistant | Resistant | |
| **Chemical resistance** | 13 | | | |
| Household chemicals & swimming pool salts | | A | Minimum A | Compliant |
| Acids and alkalis at low concentrations | | LA | Minimum LB | Compliant |
| **Stain resistance** | 14 | 5 | Minimum 3 | Compliant |
| **Light fastness** | DIN | Resistant | Resistant | Compliant |
| **Cladding photo-catalytic properties**<br>Air purification performance % NOx | ISO 22197-1 | 8.4% (Class 3) | Class 1-3 | Compliant |

*Summary of results and evaluation of the newly developed prototype*

In view of the results obtained, the tested sample can be classed as SUITABLE for use on the façade of the University of Malaga Faculty of Psychology as wall cladding in temperate climate exteriors.



**Muscle-like ceramic skin – a material with light of its own**