# TECHNICAL–ECONOMIC STUDY OF FACADE MATERIALS AND SYSTEMS

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## ABSTRACT

*The present paper presents an economic-technical study of various facade materials and systems. Given the differences in behaviour between traditional and industrialised systems, as well as the enormous variety of materials able to form the outer finish of the building, the most representative possible group of these has been analysed, taking as the fundamental premise the outer cladding material, and studying associated systems.*

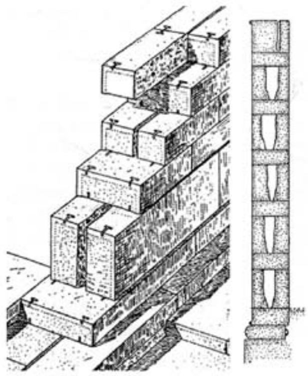
*Thus, both traditional systems (fair face, single-layer and marble panel) and ventilated facade systems (ceramics, stone, fibre-reinforced concrete and aluminium) and curtain walls (glass) have been studied, drawing up a technical comparison in terms of the characteristics of the outer cladding material and the installation system. The technical study has been completed with an economic evaluation (at basic cost estimate level), which enables establishing a quality–price ratio of the materials and systems analysed.*

## 1. INTRODUCTION. HISTORICAL EVOLUTION OF ENVELOPES.

Construction with heavy envelopes has generated most of the history of architecture: from adobe and mud and straw envelopes, via the well-known Roman *opus caementicium,* to facing brick masonry, today already traditional.

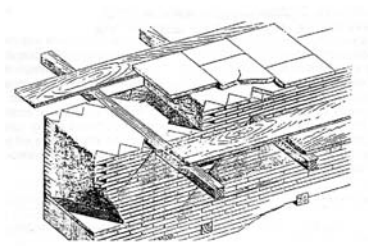
Originally, the heavy envelopes solved simultaneously the issue of envelope and structure. The triad of demands "strength, watertightness and thermal protection" were entrusted to a single material, whose shortcomings in regard to load-bearing capacity and protection against heat or moisture were compensated by making the walls thick. A local architecture was involved, conditioned by the resources of the location and the extraction and forming conditions of the different available materials.

The first walls consisting of more than one wythe date from the 7th century BC, with the well-known Greek *emplecton:* a wall defined by two wythes of stone built without mortar and perfectly fitted, dressed in their outer face, with the interior completely empty or filled with gravel and lime mortar.



*Greek wall. Emplecton technique.*

Subsequently, around the beginning of the 2nd century, the Romans introduced the *opus caementicium*, an adaptation of the Greek *emplecton*. The main difference between both types was based in the appearance of hydraulic cement: pozzolanic sand mixed with lime, forming an impermeable cement that hardened when mixed with water. With the fall of the Roman empire, pozzolana cement stopped being used and no other type of cement was used until the appearance of Portland cement, in the 19th century.



*Roman wall. Opus Caementicium*

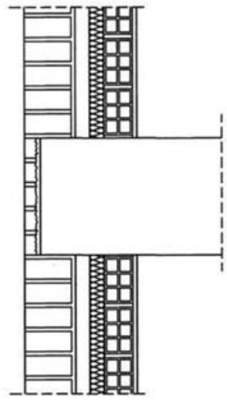
At the beginning of the 19th century, a most important step occurred in the evolution of facade construction systems, by equipping to the internal wythe with resistant capacity and leaving the outer external wythe as a mere envelope. This was the English *cavity wall,* made of an inner wall of half-foot brick on which the decks rested, and a fully independent outer wythe, which surrounded the inner wall up to the maximum height that its load-bearing capacity allowed.

With the arrival of the industrial revolution in the first years of the 19th century a radical change took place in society, in urban life and in the building methods of the turn of the century. The use of new materials such as iron or concrete opened up new constructive possibilities, dissociating the 'architect–artist' of earlier centuries from the 'architect–engineer', who initiated a new path, with the use of new materials and technologies.

The separation of the structure from the envelope in the 19th century, and the later concrete structure in the 20th century meant a definitive advance in the evolution of facade construction systems. As A Pret said in 1908:

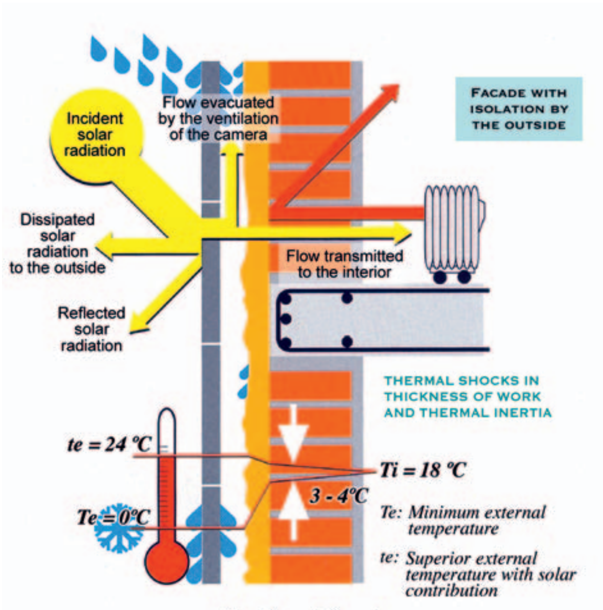
*«The great buildings of our time have a skeleton, a reinforced concrete or iron structure. The structure is to the building as the skeleton to the animal: rhythmic, balanced and symmetrical it contains and it maintains the most varied organs and most diversely located; in the same way is the structure of the building to be composed: rhythmic, balanced and also symmetrical.»*

With this differentiation of functions the cavity was released from the ties that obliged it to be part of a structural element, solely having to solve the discharge of a light element, without load bearing demands. A new type of facade appeared, seeking the specialisation of layers, one of the layers of the envelope, and which enabled new light materials to enter the fray, since they no longer needed to perform a structural function.



*Conventional*

This development has led to today's facade, now considered conventional, consisting of two brick wythes separated by an air chamber and intermediate insulation, generally held in a concrete structure. The study of the weaknesses of these systems, together with industrialisation and the great diversity of materials existing at the present time, has fostered the evolution towards technically more developed systems: *'the ventilated facade'*. This type of facade resorts to a conventional envelope, to which, by means of point mountings or a substructure, an external wythe is added with certain characteristics, thus transmitting the weight of the cladding to another wythe or the actual building structure.



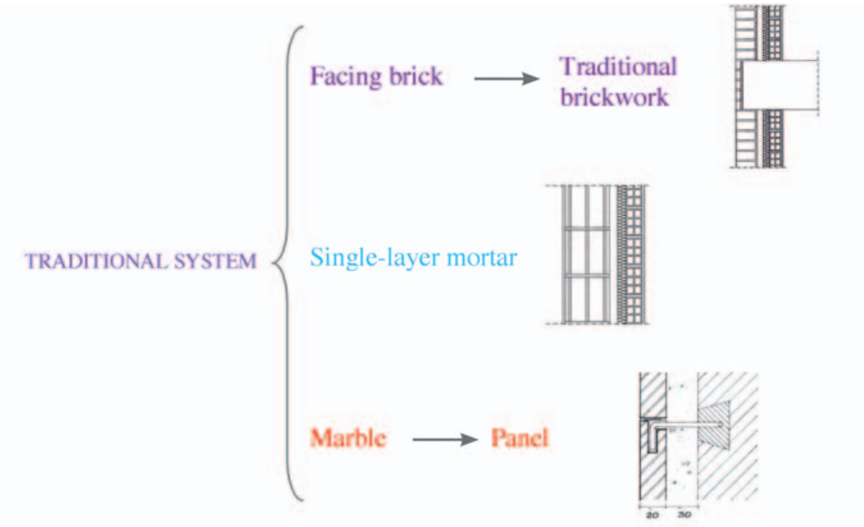

*Ventilated facade*

## 2. STUDIED FACADE MATERIALS AND SYSTEMS.

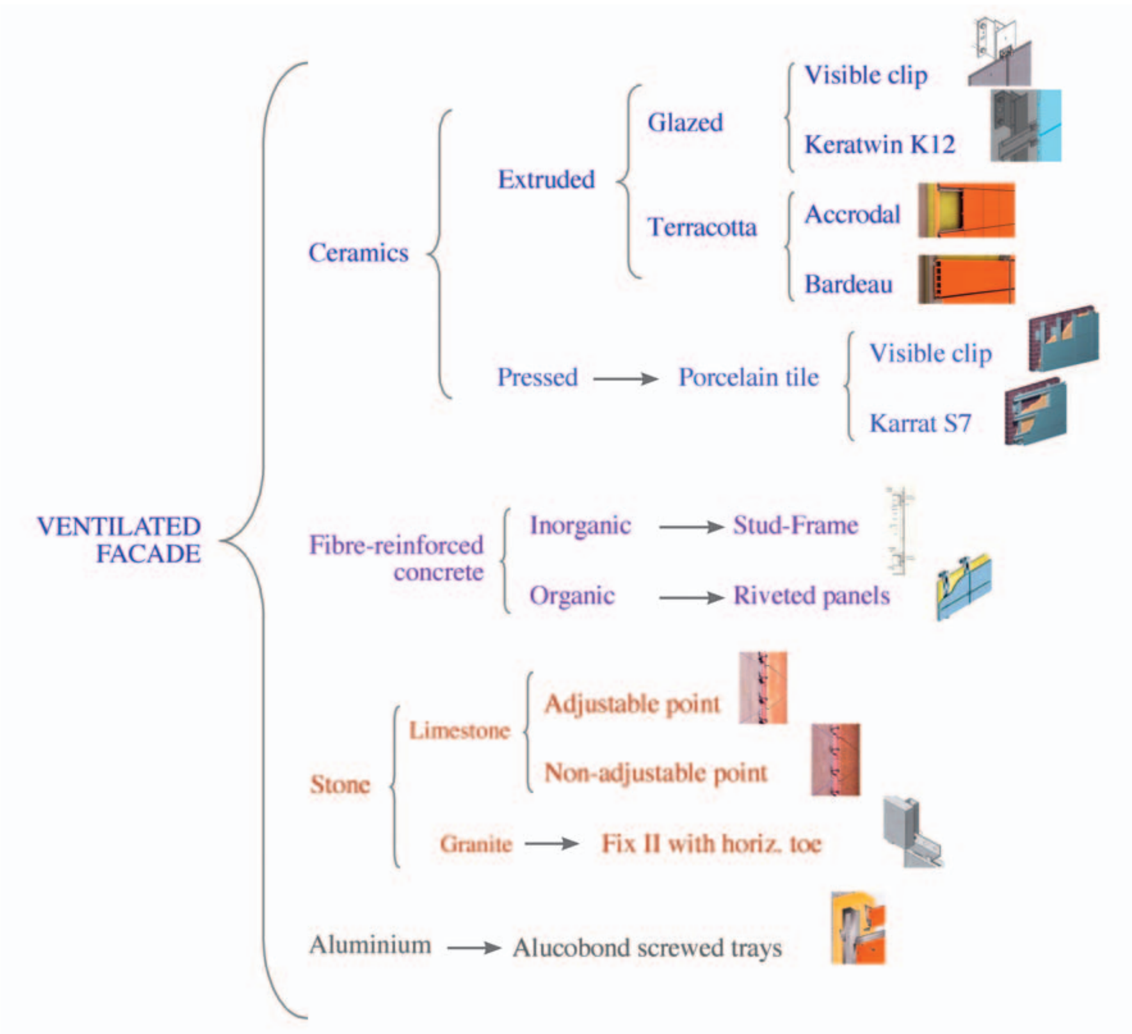
Given the differences in behaviour between the traditional facade systems and present industrialised ones, as well as the huge variety of materials that are able to form the outer finish of the building, it was decided to study the most representative possible group of these. Thus, the outer cladding material was taken as the basic premise, studying the systems associated with this.

Following that premise a distinction has been drawn between three groups: traditional, ventilated facade and curtain wall systems, observing the materials most widely used in each group. The following schemes summarise the selected materials and systems for each of these.

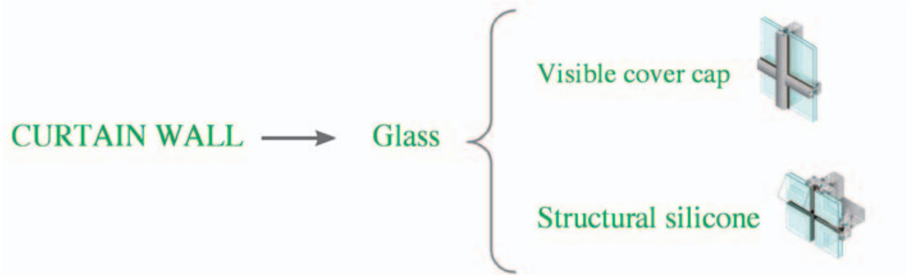
## 2.1. TRADITIONAL SYSTEMS




## 2.2. VENTILATED FACADE SYSTEMS



2.3. CURTAIN WALL SYSTEMS.




## 3. TECHNICAL STUDY

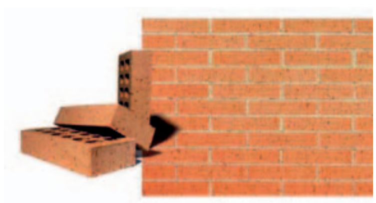
Architecture is a functional art. We need an envelope that protects us from the weather, providing a watertight, durable envelope in time, which is aesthetically pleasant and enables us to live comfortably. In short, the envelope function involves providing appropriate protection against all the outer agents, with the appropriate strength and resistance to each of these, providing habitability and inner comfort together with an aesthetic image of the building, matching its function and environment. However, in addition to all these actions, we need to consider other aspects such as correct execution, ecology or economy of the whole, evaluating its durability, holding its properties over time.

For all these reasons it becomes necessary to evaluate the characteristics of the materials and systems, with a view subsequently to being able to compare them. Although these characteristics were determined in the study, as well as the advantages and disadvantages of each, this paper will only describe the materials and systems mentioned previously.

3.1. FACING BRICK. TRADITIONAL BRICKWORK

Facing bricks are ceramic products, made up of a body of a clayey nature, whose technical characteristics depend both the manufacturing process and on the applied finish treatments. The fair face bricks used in cladding facades are mostly made by extrusion and subsequent firing, although there are also bricks formed by pressing clay powder. When the kiln firing temperature is increased and the pieces are subjected to a reducing atmosphere, clinker bricks can be made, with better technical characteristics.

***Traditional brickwork:*** **Traditional** fair-face brick facades are made by laying the bricks in courses on top of each other in an ordered form, following certain tie rules. The strength of the brickwork is obtained by bonding the bricks with a binding element: cement mortar.



The complete conventional envelope consists of an outer wall of half-foot facing brick, a ventilated air chamber 5 cm wide, thermal insulation of variable thickness and an inner back wythe with its corresponding finish.

## 3.2. SINGLE-LAYER MORTAR. CONTINUOUS COVERING

Single-layer mortar is a covering made of a cement mortar perfected for the outer cladding of facades. These single-layer mortars are made industrially, supplied ready to be mixed with water for direct application in a single layer on the envelope.

There are different types of coverings, depending on the desired final texture and colour of the mortar. The most common textures are those of sprayed aggregate and scraped finishes (fine, medium or coarse) or rustic.

***Continuous covering***: Single-layer mortar is a **continuous covering** applied directly onto the envelope wall.

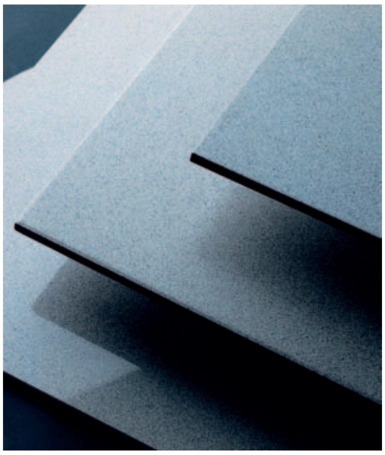
## 3.3. MARBLE. PANEL SYSTEM

Marble is a crystalline rock, fundamentally consisting of calcium carbonate ($CaCO_3$), accompanied by a great variety of other minerals: mica, silicates, iron oxides…

Marbles belong to the metamorphic type of rock, formed by the mineral and structural transformation of limestones and dolomites, by subjection to high pressures and temperatures. Different types of marbles are found, with various textures (bushhammered, pumiced, sawed, flamed and polished) and colours, depending on the quantity of the components and their grain sizes. Although the sizes used in cladding ventilated curtain walls vary, the slab surface should never exceed 1 $m^2$, since greater surfaces make them difficult to handle due to the weight. According to standard NTE RCP the minimum thickness of the slabs shall be 4 cm.

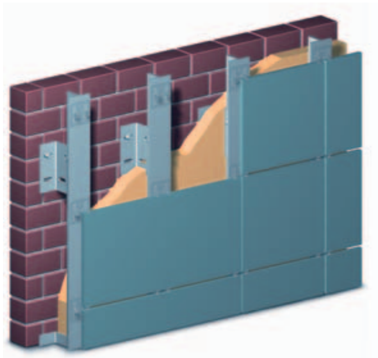
***Panel system:*** The traditional stone *Panelling* system is based on the transmission of stresses to the substrate by means of fibre-reinforced gypsum plaster paste with hooks in the edges of the slabs. The slabs are fastened by drilling four holes in the edges, where the clamps are set and then fixing the whole assembly on the wall, bedding the hooks with packing fibre-reinforced gypsum plaster in holes made in the substrate.

## 3.4. PORCELAIN TILE. VISIBLE CLIP SYSTEMS AND KARRAT S7



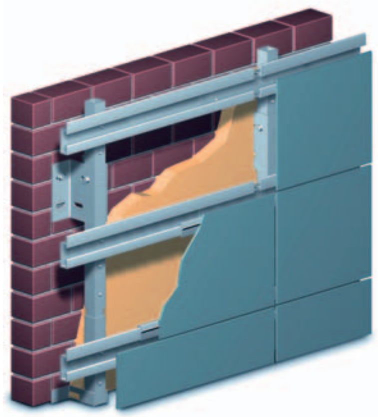
Porcelain tile is a ceramic product, made up of a body of a clayey nature whose main characteristic is its low porosity (even < 0.1%); this provides a high degree of densification, and allows achieving very high technical characteristics.

The porcelain tiles studied were made by pressing, after milling, mixing and spray drying the resulting suspension, followed by pressing at pressures of 400 kg/cm2 and firing at temperatures up to 1200 ºC. They are included in group BIa 'dry-pressed ceramic tiles with water absorption below 0.5%' of standards ISO 13006 and UNE 67 - 087.



***Visible clip system:*** The *visible clip* system fastens the tiles by means of a clip screwed to a T profile, centred at the joints of the tiles, retaining the bottom two and supporting and retaining the top ones. There are specific clips for fastening 2 tiles, used in the bottom courses or top trim.

***Karrat S7 system:*** The *Karrat S7* system is a ventilated facade system with a substructure based on the arrangement of horizontal profiles forming a network with the vertical profiles. The anchorage consists of the insertion of the aluminium profile in the tile, for which a groove is made along the length of the piece, to a maximum depth of 30% of the tile thickness at an angle of 45º, holding the piece at the top and bottom parts. In order to allow differential expansion between the aluminium and the tile an elastomer is incorporated between both materials



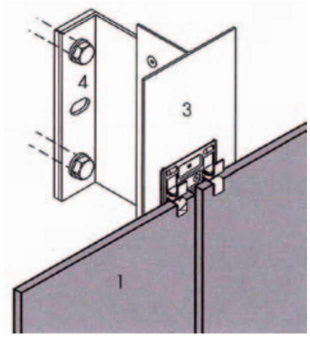
The ceramic tile is then hung from the horizontal profiles of the structure, which bear the load of the pieces (own weight and action of the wind) and transmit this to the vertical profiles which transfer it to the decks and wall by means of retaining and supporting brackets.

## 3.5. EXTRUDED GLAZED STONEWARE. VISIBLE CLIP SYSTEM

The extruded glazed stoneware tiles used in this system consist of a body of a clayey nature on which a photocatalysing hydrophilic coating is applied *(hydrotec)*, which is water and dirt repellent.

This type of tile is extruded and the hydrophilic coating is applied during glazing, after which the tile is subjected to a single firing cycle. They belong to group AI 'extruded ceramic tiles with water absorption below 3%' of standards ISO 13006 and UNE 67 - 087.

*Visible Clip System:* This system works just like the one described previously, only differing in the outer cladding material.

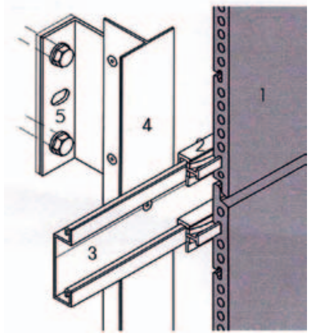


## 3.6. EXTRUDED GLAZED STONEWARE. KERATWIN K12 SYSTEM

Just as in the previous system, the extruded glazed stoneware tiles used in this system consist of a body of a clayey nature on which a photocatalysing hydrophilic coating is applied (hydrotec), which is water and dirt repellent.

This type of tile is extruded and the hydrophilic coating is applied during glazing, after which the tile is subjected to a single firing cycle. These tiles belong to group AIIa 'extruded ceramic tiles with medium–low water absorption, between 3% and 6%' of standards ISO 13006 and UNE 67 - 087.

*System Keratwin K12:* The *Keratwin K12* system is a ventilated facade system with a substructure based on the arrangement of horizontal profiles forming a network with the vertical profiles. The anchorage consists of the insertion of four clips in the back part of the tile, introduced in a T-shaped groove made during the manufacturing process. These clips then enable hanging the sheets in the horizontal profile grid fastened to the vertical substructure.

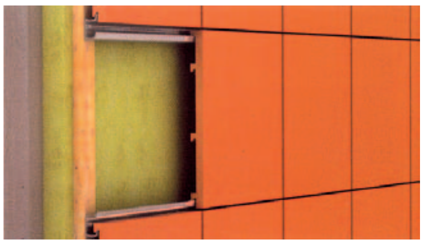


The horizontal profiles bear the load of the pieces (own weight and action of the wind) and transmit this to the vertical profiles which transfer it to the decks and wall by means of retaining and supporting brackets.

## 3.7. TERRACOTTA. ACCRODAL SYSTEM.

The Accrodal type terracotta tiles are ceramic products, made up of a body of a clayey nature, whose technical characteristics depend on both the manufacturing process and the applied finish treatments. This type of tile is made by extrusion, and may be glazed, followed by firing.

*Accrodal System:* The *Accrodal* system is a ventilated facade system with a substructure based on the arrangement of horizontal profiles forming a network with the vertical profiles. The anchorage is based on 4 longitudinal bars made in the rear of the tile during extrusion, which enable hanging the tiles directly on the horizontal profile grid, fastening them to the vertical substructure.



The horizontal profiles bear the load transmitted by the pieces (own weight and action of the wind) and transfer this to the vertical profiles, which transmit it to the decks and wall by means of the corresponding anchorages.

## 3.8. TERRACOTTA. BARDEAU SYSTEM.

The Bardeau-type terracotta tiles are ceramic products consisting of a body of a clayey nature, whose technical characteristics depend on both the manufacturing process and the applied finish treatments.

This type of tile is extruded, and may be glazed, followed by firing. These tiles belong to the AIIa group ‘extruded ceramic tiles with medium–low water absorption, between 3% and 6%’ of the standards ISO 13006 and UNE 67 - 087.

***Bardeau system:*** The *Bardeau* system is a system for the outer cladding of facades by mounting the cladding on a metallic substructure with mechanical anchorages. The tiles are fastened by installing hidden clips which, anchored to the wings of the T profile, hold the piece by their holes, retaining the bottom and supporting and retaining the top.

The clips bear the load transmitted by the pieces (own weight and action of the wind) and lead this to the vertical profiles, which transmit it to the decks and wall by means of their corresponding anchorages.

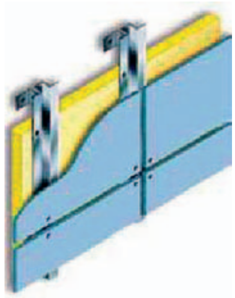
## 3.9. GLASS FIBRE-REINFORCED CONCRETE. STUD–FRAME SYSTEM

Glass fibre-reinforced concrete is a material made up of a matrix of Portland cement, reinforced with glass fibre dispersed throughout its mass. The cement contributes mouldability and compression strength, while the glass fibre AR (resistant to alkalis) provides the panel with tensile strength. The panels used in cladding facades are made by spraying, previously mixing the cement and the aggregate with water and spraying them together with cut glass fibre strands (of the order of 5%, uniformly distributed in the mass).

***Stud–frame system:*** The *Stud-frame* type panels are made up of a concrete sheet with fibres 10 mm thick, set in a metallic frame, forming a panel with a total thickness of 120 mm. These panels are installed by mounting them on backings or auxiliary structures, needed for proper fastening.

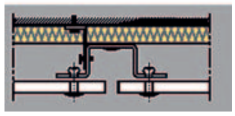
## 3.10. ORGANIC FIBRE-REINFORCED CONCRETE. RIVETED SHEET SYSTEM

Organic fibre-reinforced concrete is a material made up of a Portland cement matrix, reinforced with natural organic fibres and other charges, dispersed throughout the mass. The cement contributes mouldability and compression strength, while the fibres provide tensile strength. Different types of sheets are found, with various textures (sandpapered, damp-proofed…) and colours, obtained by pigment addition to the mass or application of a mineral paint.



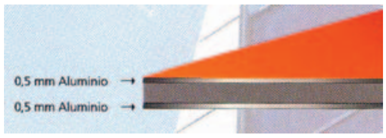
The panels used in facade cladding are made by pressing, after proportioning and mixing the raw materials, and are subsequently introduced in the autoclave, where the setting is completed.

***Riveted sheet system:*** As the name indicates, in the *Riveted sheet* system these are fastened by rivets to the substructure, which consists of metallic studs, anchored to the underlying facade by means of adjustment squares. The gap left between the diameter of the hole and the rivet in all the mountings except the centre one in the sheet is characteristic of the system, and this centre rivet is the fixed anchorage point.



3.11. ALUMINIUM. ALUCOBOND SCREWED TRAY SYSTEM

Aluminium is a metal used in the elaboration of composite facade panels of the Alucobond type, formed by two aluminium sheets 0.5 mm thick of 5.005 alloy and PE core. Different types of panels are found with various finishes (thermolacquered, anodised and natural) and colours.




***Alucobond screwed tray system***: The *screwed tray system* is a ventilated facade system with a substructure, based on mounting formed trays of Alucobond panels to a substructure by means of anchorages. The trays are made by cutting and folding the panels, obtaining four flanges that fold and are joined by rivets, using small plates or squares for rigidification. The sheets are fixed to the substructure by means of stainless steel or aluminium self-blocking bolts in grooves that allow free expansion in the horizontal direction.

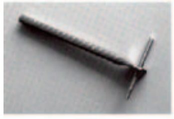
The bottom panels are bolted to the substructure, while the top ones are fitted on. A clip of the same material is set between both elements to leave sufficient room for free expansion of the trays in the vertical direction.

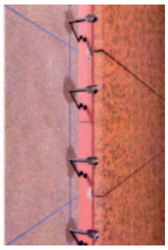
3.12. LIMESTONE. NON-ADJUSTABLE AND ADJUSTABLE POINT SYSTEMS

Limestone is a rock with a basic character, consisting mainly of calcium carbonate ($CaCO_3$), accompanied by magnesium carbonate and other impurities like sand, iron oxides…

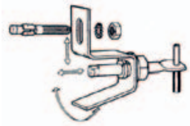
Limestones belong to the sedimentary types of rocks, formed by chemical precipitation of calcium carbonate in marine environments, under the action of biological and chemical factors. There are different types of limestones, with various textures (bushhammered, pumiced, sawed, flamed and polished), colours and properties. Although the sizes used in cladding ventilated facades are varied, the area of the slabs should never exceed 1 m$^2$, since larger surfaces make handling difficult due to the weight. According to standard NTE RCP slab minimum thickness shall be 4 cm.

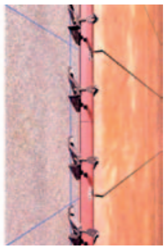
***Non-adjustable point system***: The *fixed point anchorage* system is based on the transmission of stresses to the substrate by means of embedded anchorages, set in holes made in the base and retouched with fast-setting mortar. Plumb and flatness are obtained by the difference in diameter between the hole and anchorage. The slabs are fastened by drilling four holes at their edges.





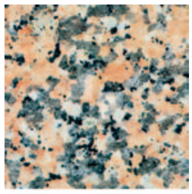
A***djustable point system***: The *adjustable anchorage point* system is a system for the outer cladding of facades based on the transmission of stresses to the substrate by mechanically fixed anchorages in the base. It has a system for adjustment in the three directions for proper plumb and flatness. The slabs are fastened by drilling four holes at their edges.



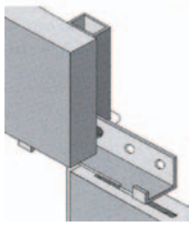


## 3.13. GRANITE. FIXII SYSTEM WITH HORIZONTAL TOE

Granite is a crystalline rock, consisting of different quantities of quartz, feldspar and mica, whose main characteristic is its low porosity (below 0.5%); thus, it has a high degree of densification and very high technical characteristics.



There are different types of granites, with various textures (bushhammered, pumiced, sawed, flamed and polished) and colours, depending on the quantities of components and their grain sizes. Although the sizes used in cladding ventilated facades are varied, the area of the slabs should never exceed 1 m$^2$, since larger surfaces make handling difficult due to the weight. According to standard NTE RCP slab minimum thickness shall be 3 cm.



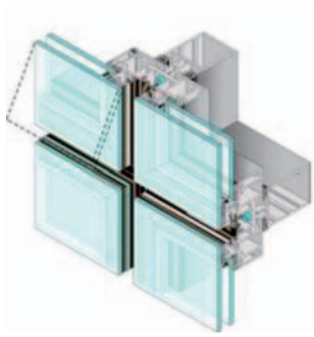
***FIX II system with horizontal toe:*** The *FIX II* system with angles of the *horizontal toe* type is a system for facade outer cladding by mounting the slabs on a metallic substructure with anchorages. The slabs are fastened by installing a profile at an angle with a horizontal toe fastened to the vertical substructure, which retains the bottom two slabs and supports and retains the top ones.

## 3.14. GLASS. SYSTEMS WITH VISIBLE COVER CAP AND STRUCTURAL SILICONE.

Curtain walls are light envelopes, made up of a set of interconnected vertical and horizontal metallic elements, between which fill-in elements form a continuous surface that limits the inner space. This type of envelope is suspended from the deck, and runs in front of the structure. Curtain walls are characterised by the predominant use of glass, fixed on an aluminium substructure.

***Visible cover cap system:*** *Visible cover cap* systems are made up of studs and horizontal crosspieces, visible from the outside. This frame then serves to mount the glass and panels, held by small plates, under pressure.

The studs are fastened to the decks of the building, transmitting both the own weight of the envelope and the outer actions withstood by this. The crosspieces are then anchored on these, whose function is to support and transmit the loads of the elements that bear on them. In the viewing areas double glazing is used, whereas in the opaque areas (railings, deck transitions …) simple glasses and insulating back panels are used, with a black lining on one of their sides.



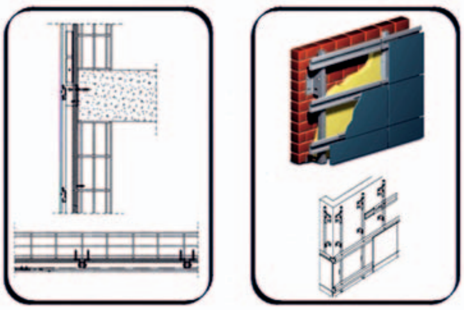
***Structural silicone system:*** *Structural silicone* systems are characterised by hiding the base profiling, fixing the glasses to the supporting grid by means of silicones with special characteristics.

The studs are fixed to the decks of the building, transmitting both the own weight of the envelope and the outer actions withstood by this. The crosspieces are then anchored on these, whose function is to support and transmit the loads of the elements of the envelope. In order to avoid cutting the silicone with the weight of the glass, the glass is supported by glazing wedges, so that the function of the silicone is reduced to avoiding detachment by actions perpendicular to the envelope (wind…).

## 4. ECONOMIC STUDY.

ECONOMIC STUDY

Porcelain Tile. Karrat S7 system

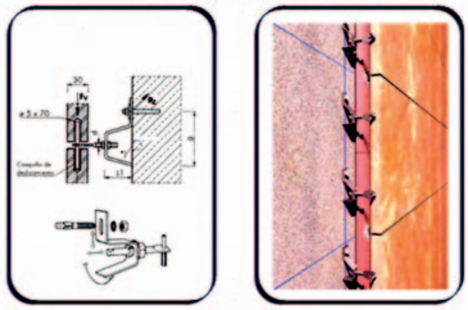


| System €/m² | | | | |
|---|---|---|---|---|
| Material | System | Labour | Various | TOTAL |
| 51.68 | 47.45 | 36.80 | 2.20 | 138.13 |

| Envelope €/m² | | | | | |
|---|---|---|---|---|---|
| System | Thermo-clay | PU Ins. | Plaster | Paint | TOTAL |
| 138.13 | 31.32 | 6.42 | 10.03 | 4.58 | 190.48 |

ECONOMIC STUDY

Limestone. Adjustable point system



| System €/m² | | | | |
|---|---|---|---|---|
| Material | System | Labour | Various | TOTAL |
| 38.29 | 26.13 | 55 | 7.47 | 126.89 |

| Envelope €/m² | | | | | |
|---|---|---|---|---|---|
| System | Thermo-clay | PU Ins. | Plaster | Paint | TOTAL |
| 126.89 | 31.32 | 6.42 | 10.03 | 4.58 | 179.23 |

With a view to obtaining a quality–price ratio, the technical study was completed with an economic study of the materials and facade systems analysed. The section is structured in the form of data files, shown below, which include both the cost of the cladding and that of the overall envelope.

However, it is of importance to note that, whereas the cost estimates of the traditional systems were obtained from databases, in the ventilated facade and curtain wall systems the cost was supplied by the manufacturers of the different materials or taking even that of the own installation system. Therefore, it is necessary to note that basic, orientational prices are involved, but not definitive ones, because they generally do not include trims, and some estimates were provided in a global way. With the data obtained a table has been drawn up summarising the economic study, of which a part follows:

| Nº | MATERIAL | SYSTEM | SYSTEM | ENVELOPE | SYSTEM DEV. | ENVEL. DEV. |
|---|---|---|---|---|---|---|
| 1 | Facing brick | Conventional | 33,26 | 78,51 | -0,70 | -0,57 |
| 2 | Single layer | Scraped dressed | 18,65 | 83,41 | -0,83 | -0,55 |
| | | Scraped fine | 19,73 | 84,49 | -0,82 | -0,54 |
| | | Sprayed aggregate | 20,62 | 85,38 | -0,81 | -0,54 |
| 3 | Marble | Traditional | 99,71 | 145,64 | -0,10 | -0,21 |
| 4 | Porcelain tile | Visible clip | 116,68 | 169,03 | 0,05 | -0,08 |
| 5 | | Karrat S7 | 138,13 | 190,48 | 0,24 | 0,03 |
| 6 | Extruded Ceramics | Visible clip | 114,53 | 166,88 | 0,03 | -0,09 |
| 7 | | Keratwin K12 | 159,56 | 211,91 | 0,43 | 0,15 |

## 5. TECHNICAL-ECONOMIC COMPARATIVE STUDY.

In order to compare the different materials and systems both separately and jointly, a technical-economic comparative study has been made based on different tables, in which each characteristic has been weighted as a function of its relative importance for use in the facade, subsequently determining its degree of suitability and compliance for each particular material and system.

Based on the compiled information a first table was drawn up with the technical characteristics of the materials under study, then making another simplified one to facilitate data comparison. The last table details the characteristics of the different studied systems, again considering (although with a lower score) the holding of the material properties, given their strong relation with the system (not all the systems would be possible with all the materials), in addition, taking the durability of the whole to depend on the outer cladding material. As may be observed, in regard to cost other characteristics of interest have also been considered, thus obtaining a new relative score based on which a comprehensive evaluation can be obtained of MATERIAL–SYSTEM–PRICE.

Tables: technical characteristics of the materials and simplified table.

| CARACTERÍSTICAS TÉCNICAS | PESO | Lad. Caravista (1) | | M. Monocapa (2) | | G. Porcelánico prensado – G. Porcel. TAU (3) | | Gres esmaltado – Keralon | |
|---|---|---|---|---|---|---|---|---|---|
| Peso (Kg/m²) | 11,5 | 138.5 - 155 * UNE 67.030 | 0,5 | 17 | 1 | 22 - 27 | 0,8 | 18 | 0,9 |
| Comp. Al fuego | 4 | M0 NBE CPI - 96 | 1 | M0 NBE CPI - 96 | 1 | M0 NBE CPI - 96 | 1 | M0 NBE CPI - 96 | 1 |
| Módulo Elástico (N/mm²) | No | - | - | 3200-16000 | - | 13334 | - | - | - |
| R. Flexión: | 17,3 | | | | | | | | |
| Módulo de rotura (N/mm²) | 13,3 | - | - | 3 - 4.5 | 0,6 | 40-63 UNE 10.545-4 | 1 | >30 | 0,8 |
| Espesor (mm) | 3 | 40 - 50 - 70 | | 10 -- 15 | | 10 -- 12 | | 8 | |
| Fuerza (Kg) | 1 | - | | - | | 280 - 650 | | - | |
| R. Impacto (cm); Rotura + deformación. | 8 | - | 1 | 2.2 | 0,8 | - UPEC | 0,7 | - | 0,7 |
| R Tracción (N/mm²) | No | - | - | 2.5 - 4 | - | - | - | - | - |
| R. Compresión (N/mm²) | 17,3 | 20-65 UNE 67.026 | 0,8 | 6.5--21 | - | - | - | - | - |
| Dilatación térmica lineal ($°C^{-1} \cdot 10^{6}$) | 5 | 5--8 | 1 | - | 0,7 | 6 UNE 10.545-8 | 1 | 6 UNE 10.545-8 | 1 |
| Comportamiento frente al agua: | 21,3 | | | | | | | | |
| Absorción de agua (%) | 18,8 | 3--18 UNE 67.027 | 0,7 | - | 0,7 | < 0.1 UNE 10.545-3 | 1 | < 3 UNE 10.545-3 | 0,9 |
| R. a la helada (%). | 2,5 | NO Helad. UNE 67.028 | | - | | ALTA UNE 10.545-12 | | - | |
| Mantenimiento de propiedades (8): Resistencia a las manchas. Corrosión en niebla salina. Atmósfera de $SO_2$. Envejecimiento radiación solar. | 13,5 | MEDIO | 0,7 | MEDIO | 0,7 | ALTO | 1 | ALTO | 0,9 |
| OTRAS CARACTERÍSTICAS | | | | | | | | | |
| Posibilidades estéticas. | 10 | MEDIO | 0,8 | ALTO | 1 | ALTO | 1 | ALTO | 1 |
| Homogeneidad del material. | 9,4 | MEDIO | 0,8 | MEDIO | 0,7 | ALTO | 1 | ALTO | 1 |
| PUNTUACIÓN TOTAL | 100 | 76,47 | | 76,72 | | 95,3 | | 89,51 | |

*NOTA: evaluación según comportamiento del material.*

| CARACTERÍSTICAS TÉCNICAS | PESO | Lad. Caravista | | | M. Monocapa | | | G. Porcelánico prensado – G. Porcel. TAU | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Peso (Kg/m²) | 11,5 | BAJO | 0,5 | 5,75 | ALTO | 1 | 11,5 | MEDIO/ALTO | 0,8 | 9,2 |
| Comp. Al fuego | 4 | ALTO | 1 | 4 | ALTO | 1 | 4 | ALTO | 1 | 4 |
| Módulo Elástico (N/mm²) | No* | NO POND. | - | - | NO POND. | - | - | NO POND. | - | - |
| R. Flexión: Módulo de rotura (N/mm²); Espesor (mm); Fuerza (Kg) | 17,3; 13,3; 3; 1 | NO PONDERA | - | - | BAJO | 0,6 | 10,38 | ALTO | 1 | 17,3 |
| R. Impacto (cm); Rotura + deformación. | 8 | ALTO | 1 | 8 | MEDIO | 0,8 | 6,4 | BAJO | 0,7 | 5,6 |
| R Tracción (N/mm²) | No | NO POND. | - | - | NO POND. | - | - | NO POND. | - | - |
| R. Compresión (N/mm²) | 17,3 | MEDIO (1) | 0,8 | 13,84 | NO POND. | - | - | NO POND. | - | - |
| Dilatación térmica lineal ($°C^{-1} \cdot 10^{6}$) | 5 | ALTO | 1 | 5 | MEDIO | 0,7 | 3,5 | ALTO | 1 | 5 |
| Comportamiento al agua: Absorción de agua (%); R. a la helada (%) | 21,3; 18,8; 2,5 | MEDIO | 0,7 | 14,91 | MEDIO (2) | 0,7 | 14,91 | MUY ALTO | 1 | 21,3 |
| Mantenimiento de propiedades: Resistencia a las manchas. Corrosión en niebla salina. Atmósfera de $SO_2$. Envejecimiento radiación solar. | 13,5 | MEDIO | 0,7 | 9,45 | MEDIO | 0,7 | 9,45 | ALTO | 1 | 13,5 |
| OTRAS CARACTERÍSTICAS | | | | | | | | | | |
| Posibilidades estéticas. | 10 | MEDIO | 0,8 | 8 | ALTO | 1 | 10 | ALTO | 1 | 10 |
| Homogeneidad del material. | 9,4 | MEDIO | 0,8 | 7,52 | MEDIO (2) | 0,7 | 6,58 | ALTO | 1 | 9,4 |
| PUNTUACIÓN TOTAL | 100 | 76,47 | | | 76,72 | | | 95,3 | | |

*NOTA: evaluación según comportamiento del material.*

Tables: technical characteristics of the systems and overall comparison.

| CARACTERÍSTICAS | PESO | Lad. Caravista – Fáb. Caravista | | | M. Monocapa – Rev. Monocapa | | | G. Porcelánico prensado – Grapa Vista | | | G. Porcelánico prensado – Karrat S7 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EJECUCIÓN.- | 33 | | | | | | | | | | | | |
| Llave en mano, OT / Sist. homologado | 11 | NO | 0,6 | 6,6 | NO | 0,6 | 6,6 | SI | 1 | 11 | SI | 1 | 11 |
| Sistema industrializado | 9 | NO | 0,8 | 7,2 | NO | 0,8 | 7,2 | SI | 1 | 9 | SI | 1 | 9 |
| Flexibilidad | 6 | ALTO | 1 | 6 | ALTO | 1 | 6 | MEDIO | 0,7 | 4,2 | MEDIO | 0,7 | 4,2 |
| Rendimiento | 7 | BAJO | 0,6 | 4,2 | MEDIO | 0,8 | 5,6 | ALTO | 1 | 7 | ALTO | 1 | 7 |
| COMPORTAMIENTO.- | 47 | | | | | | | | | | | | |
| Tensiones en el material de revestimiento: | 15,5 | BAJO | 0,6 | 9,3 | MEDIO | 0,8 | 12,4 | MEDIO | 0,8 | 12,4 | ALTO | 1 | 15,5 |
| Movimientos higrotérmicos. | | ALTOS | | | - | | | BAJOS | | | BAJOS | | |
| Facilidad de regulación. | | - | | | - | | | ALTA | | | ALTA | | |
| Mecanizado. | | - | | | - | | | NO | | | REVERSO | | |
| Tipo de anclaje. | | - | | | - | | | PUNTUAL | | | CONTINUO | | |
| Puentes térmicos. | 4 | SI | 0,6 | 2,4 | SI | 0,6 | 2,4 | NO | 1 | 4 | NO | 1 | 4 |
| Cámara ventilada. | 7,5 | SI - NO | 0,8 | 6 | SI - NO | 0,8 | 6 | SI | 1 | 7,5 | SI | 1 | 7,5 |
| Riesgo de rotura por impacto. | 5 | ALTO | 1 | 5 | MEDIO | 0,8 | 4 | BAJO | 0,7 | 3,5 | BAJO | 0,7 | 3,5 |
| Seguridad en caso de rotura. | 12,5 | ALTO | 1 | 12,5 | MEDIO | 0,8 | 10 | ALTO | 1 | 12,5 | ALTO | 1 | 12,5 |
| Sistema visto - oculto. | 2,5 | VISTO | 0,7 | 1,75 | OCULTO | 1 | 2,5 | VISTO | 0,8 | 2 | OCULTO | 1 | 2,5 |
| MANTENIMIENTO.- | 20 | | | | | | | | | | | | |
| Mantenimiento: | 14,5 | | | 11,3 | | | 11,3 | | | 14,5 | | | 14,5 |
| Facilidad de limpieza. | 2,5 | MEDIO | 0,8 | 2 | MEDIO | 0,8 | 2 | ALTO | 1 | 2,5 | ALTO | 1 | 2,5 |
| Inspecciones periódicas. | 4,5 | NO | 0,9 | 4,05 | NO | 0,9 | 4,05 | NO | 1 | 4,5 | NO | 1 | 4,5 |
| Envejecimiento del material. | 7,5 | MEDIO | 0,7 | 5,25 | MEDIO | 0,7 | 5,25 | ALTO | 1 | 7,5 | ALTO | 1 | 7,5 |
| Facilidad de sustitución en caso de rotura. | 5,5 | BAJO | 0,6 | 3,3 | BAJO | 0,6 | 3,3 | ALTO | 1 | 5,5 | ALTO | 1 | 5,5 |
| OTROS.- | | | | | | | | | | | | | |
| Tiempo obtención presupuesto. | No | Bases datos | | | Bases datos | | | 2 semanas | | | 2 semanas | | |
| Asistencia técnica. | No | Sist. Estandariz. Existe mucha documentación. | | | Sist. Estandariz. Existe mucha documentación. | | | ALTA. Atención muy elevada, con definición completa de las características técnicas de materiales y sistemas. | | | ALTA. Atención muy elevada, con definición completa de las características técnicas de materiales y sistemas. | | |
| PUNTUACIÓN TOTAL | 100 | 75,55 | | | 77,3 | | | 93,1 | | | 96,7 | | |

*NOTA: evaluación según comportamiento del material.*

*(1) Asistencia técnica.*

*(2) Existen algunas empresas que proporcionan un servicio llave en mano.*

*(3) Se penaliza la gran deformabilidad del alucobond ante la acción de pequeñas cargas.*

*(4) Aunque existe cámara, en la práctica no suele ser ventilada.*

| COSTE: | PESO | Fáb. Caravista | | | Rev. Monocapa | | | Grapa Vista | | | Karrat S7 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ayudas en obra. | 20 | SI | 0,5 | 10 | SI | 0,5 | 10 | NO | 1 | 20 | NO | 1 | 20 |
| De sistema. | 65 | 33,26 | 1 | 65 | 19,67 | 1 | 65 | 116,88 | 0,7 | 45,5 | 138,13 | 0,6 | 39 |
| De cerramiento. | 65 | 78,51 | - | - | 80,74 | - | - | 169,03 | - | - | 190,48 | - | - |
| De sustitución. | 15 | MEDIO | 0,8 | 12 | MEDIO | 0,8 | 12 | BAJO | 1 | 15 | BAJO | 1 | 15 |
| PUNTUACIÓN TOTAL | 100 | 87 | | | 87 | | | 80,5 | | | 74 | | |

| MATERIAL | SYSTEM | MATERIAL | SYSTEM | MAT+SYST | 50% MAT+SYST – 50% COST |
|---|---|---|---|---|---|
| Facing brick | Conventional | 76,47 | 75,55 | 152,02 | 119,51 |
| Single layer | Continuous covering | 76,72 | 77,3 | 154,02 | 120,51 |
| Marble | Traditional panelling | 70,11 | 75,2 | 145,31 | 144,405 |
| Porcelain tile | Visible clip | 95,3 | 93,1 | 188,4 | 134,45 |
| | Karrat S7 | 95,3 | 96,7 | 192 | 133 |
| Extruded ceramics | Visible clip | 89,51 | 92,35 | 181,86 | 131,18 |
| | Keratwin K12 | 88,36 | 94,4 | 182,76 | 125,13 |
| Terracotta | Accrodal | 77,28 | 89,85 | 167,13 | 127,065 |
| | Bardeau | 74,58 | 86,3 | 160,88 | 114,19 |
| Fibre glass concrete | Stud-Frame | 67,45 | 79,5 | 146,95 | 110,725 |
| Organic fibre concrete | Riveted sheets | 70,06 | 85,75 | 155,81 | 126,28 |
| Aluminium | Screwed trays | 79,85 | 92,4 | 172,25 | 123,125 |
| Limestone | Non-adjustable point | 70,11 | 71,6 | 141,71 | 107,855 |
| | Adjustable point | 70,11 | 73,85 | 143,96 | 108,98 |
| Granite | FIX II with horiz. toe | 76,12 | 85,65 | 161,77 | 112,885 |
| Glass | Visible cover cap | 95,3 | 86,85 | 182,15 | 121,825 |
| | Structural silicone | 95,3 | 84,2 | 179,5 | 115,625 |

| | |
|---|---|
| Max. | Maximum suitability for use |
| Med–high | Medium–high suitability for use |
| Med–low | Medium–low suitability for use |
| Low | Low suitability for use |
| Min. | Min. suitability for use |

## 6. CONCLUSIONS.

According to the comparative study conducted, the materials obtaining the **highest score** have been **Porcelain Tile** and **glass**, due to their high technical characteristics and the holding of their properties in time, as a result of practically non-existent porosity. The group of **mean–high** suitability includes **glazed ceramics**, because the glaze facilitates cleaning, preventing water absorption by the material and thus increasing the holding of its properties in time. It scores lower than the previous group due to its internal porosity (between 3 and 6%), which provides it with lower mechanical properties.

According to the criteria considered **aluminium** would be the **third** material in order of suitability for outer use, because it enjoys medium holding of properties in time, while its bending strength (owing to high deformation) and thermal expansion are its main deficiencies. Materials like **facing brick, single-layer mortar, terracotta** and **granite** belong to the group with **reduced properties** for a facade use. Finally, the group of materials that has obtained the **lowest score** includes **limestones, marbles and fibre-reinforced concrete**: materials characterised by a high degree of aging in time and medium and even low mechanical characteristics; in all of these the pH is basic, which influences their degradation (acid rain…) and cleanability.

As far as the studied systems are concerned, **the best one** for the installation of facade cladding is **Karrat S7,** because it is an industrialised system, guaranteed by a DIT from the Eduardo Torroja Institute, with hidden and continuous anchorage in the rear of the tile, which is why the stresses generated in the material are minimum, while simultaneously contributing safety in case of failure. On the other hand, these initial properties are held perfectly in time due to the characteristics of porcelain tile. Similar to this system is **Keratwin K12**, with a slightly lower score, because although the anchorage is incorporated in the rear of the piece, it is not continuous, but can be described as 'semi-continuous' with four small load distribution surfaces.

The **visible clip** and Alucobond **screwed tray** systems follow in the classification. Both their properties are similar, with a medium level of stresses as a result of point anchorage in a non-machined piece. In the screwed tray system the most important characteristic to be considered is impact resistance, since, given the deformability of aluminium, the measures to be taken to reduce the effect of impact are not too effective.

The group described as **medium–low** in terms of their suitability for use includes the **Accrodal and Bardeau** systems of terracotta, **FIX II with horizontal toe** for granite, curtain wall with **visible cover cap** and **riveted sheets** of concrete reinforced with organic fibres. With regard to this last system, note how the behaviour of the material determines the system's aesthetics and holding of properties: soiling, and hygrothermal movements that even cause bulging…

The **penultimate** group of the classification includes the **Stud-Frame** system with glass fibre-reinforced concrete, **continuous monolayer** claddings and curtain wall with **structural silicone.** All of these are systems are without a ventilated air chamber and, with the exception of the curtain wall, exhibit strong degradation in time. It is of particular importance to note the classification to which the structural silicone curtain wall is relegated, since although glass displays suitable behaviour as a material, these systems have strong shortcomings in regard to thermal comfort, needing periodic inspection and not enjoying flexibility in their adaptation to variations in the building work.

The **last place** in the classification belongs to **facing brickwork, traditional panelling** with marble and limestone claddings, **with adjustable and non-adjustable point anchorage**, all characterised by producing strong stresses in the material, which can lead to degradation: failure, cracks… However, among all of these the **lowest score** in regard to the systems corresponds to the **NON-adjustable point**, since the efficiencies in the building work are reduced and the difficulty of adjustment increases the level of stresses in the material.

Finally the results can be analysed of the *overall comparison*, according to which **the best MATERIAL–SYSTEM ratio in regard to use in facades corresponds to PORCELAIN TILE** with the **KARRAT S7 system**. In addition, considering the cost, the two suitable systems are those that use **PORCELAIN TILE** as outer cladding material, which hold **the best MATERIAL–SYSTEM–COST ratio,** and the **visible clip** system, although with a slight difference in respect of **Karrat S7.**

The group with **mean–high** suitability includes **glazed ceramics** with the respective **visible clip and Keratwin** systems, as well as the curtain wall systems, both with **visible cover cap** and **structural silicone**. However, when considering the costs, the visible cover cap system would go to the medium–low group, whereas in the structural silicone system the price is so high that it would enter the low suitability group.

In the group of **medium–low** performances are the **Accrodal terracotta and Alucobond screwed tray** systems. Finally, displaying **reduced suitability** for use in facades are the systems of **facing brickwork, single-layer mortar, Bardeau terracotta, granite with substructure and riveted concrete sheets reinforced with organic fibre.** Note that in regard to this last system in the group, given its low price, its properties at material-system-cost level could be considered high; however it should be stressed that because of the characteristics of the material and installation system, its material–system score has dropped: high water absorption, reduced holding of properties, high stresses in the material…

Last, and displaying the worst performance for facade use, are the systems of **traditional marble panelling, limestone systems (adjustable and non-adjustable point) and Stud–Frame with concrete reinforced with glass fibre,** all with reduced holding of properties in time.

In short it may be concluded that, in regard to materials, glass fibre-reinforced concrete is the material with the **worst properties** for assuring good performance in facade use, whereas **Porcelain Tile and glass show suitable performance.** Note, in addition that **the systems related to Porcelain Tile present the BEST MATERIAL–SYSTEM–COST RATIO**, in regard to facade cladding use, whereas the worst overall characteristics **correspond to the fibre glass-reinforced concrete (Stud-Frame) and the point adjustable and non-adjustable limestone systems.**

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