Luz Hotel in Castellón, Spain. The façade features TAU porcelanic tiles installed with the Karrat S7 system.

TECHNICAL–ECONOMIC STUDY OF FACADE MATERIALS AND SYSTEMS

by Lucía Reig Cerda

Student of ETSGE. Polytechnic University of Valencia (UPV). Spain. Tutored by Ángel M. Pitarch (UPV); Miguel de Morlan and Carlos Sanchis (TAU Cerámica).

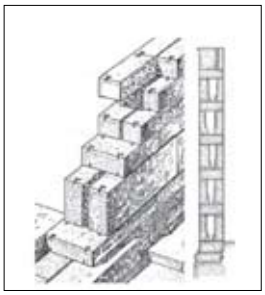
This article presents an economic-technical study of various facade materials and systems. Given the differences in behaviour between traditional and industrialised systems, as well as the enormous variety of materials able to form the outer finish of a building, the most representative possible group 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 provides a quality–price ratio of the materials and systems analysed.

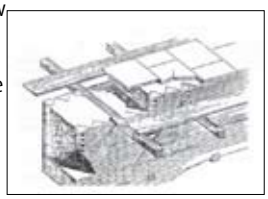
HISTORICAL EVOLUTION OF ENVELOPES

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, which is now regarded as 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.



Greek wall. Emplecton technique.

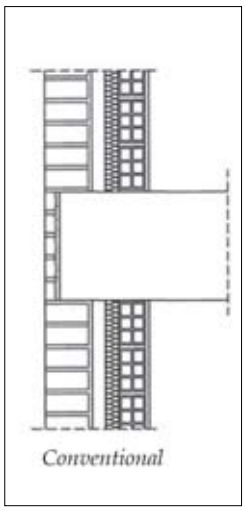


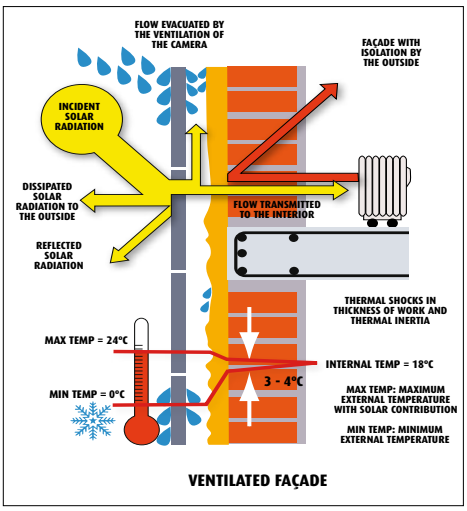
Roman wall. Opus Caementicium.

The first walls consisting of more than one width date from the 7th century BC, with the well-known Greek technique: a wall defined by two spans of stone built without mortar perfectly aligned, with a dressed outer face. The interior was hollow or filled with gravel and lime mortar.

Subsequently, around the beginning of the 2nd century, the Romans introduced the opus caementicium, an adaptation of the Greek structure. The main difference between both types was 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 ceased to exist and no other type of cement was used until the appearance of Portland cement, in the 19th century.

At the beginning of the 19th century, a most important step occurred in the evolution of facade construction systems. The arrival on the scene of the English cavity wall, made of an inner wall of brick on which the decks rested, and a fully independent outer structure, 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, disassociating 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 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."

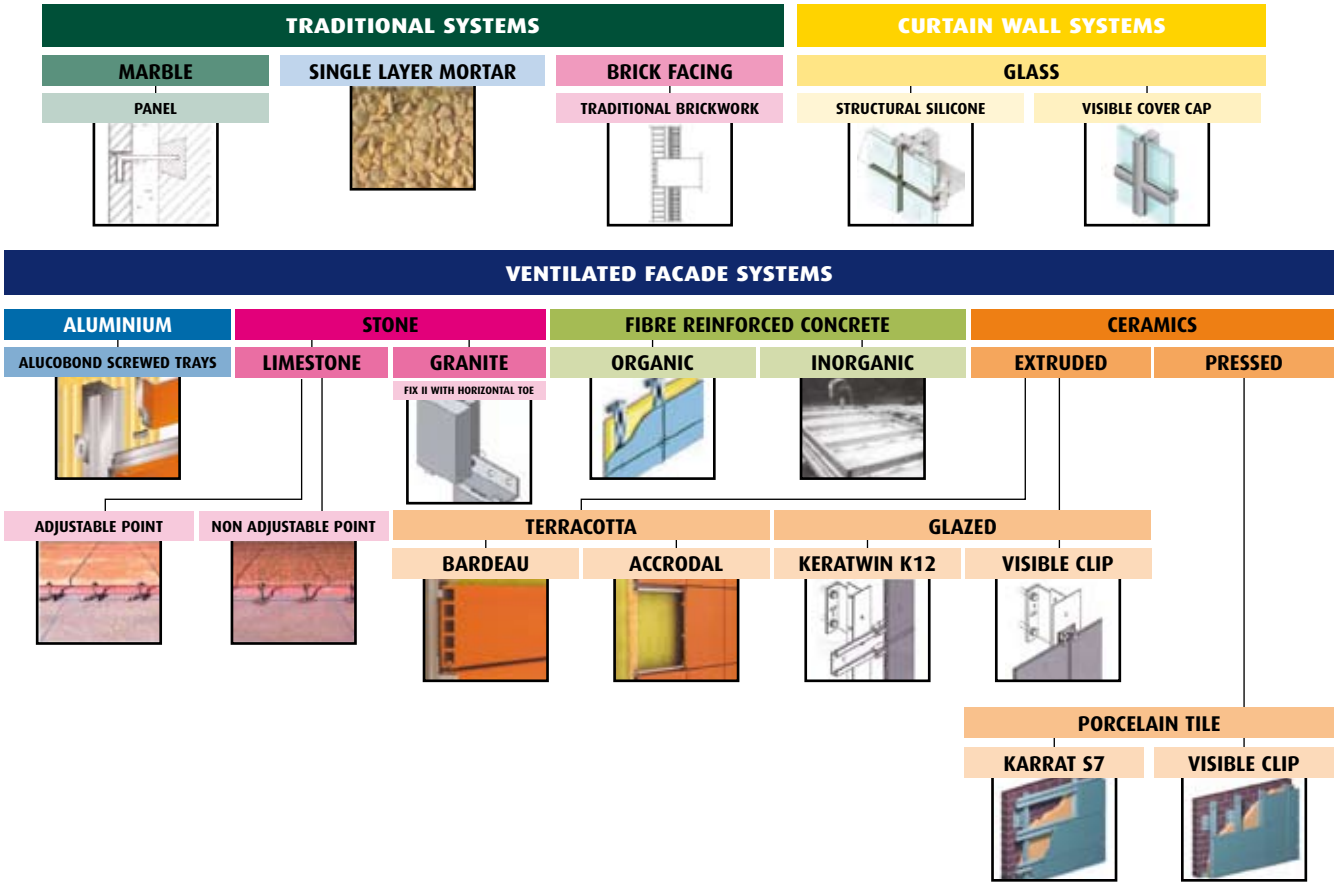
With this differentiation of functions the cavity was released from the ties that obliged it to be part of a structural element, solely having to solve the discharge of a light element, without load bearing demands. A new type of facade appeared, comprising of a series of layers. One of the layers was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

This development has led to today's façade, now considered conventional, consisting of two brick courses separated by an air chamber and intermediate insulation, generally contained 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 framing is added with certain characteristics, thus transmitting the weight of the cladding to another element or the actual building structure.

STUDIED FACADE MATERIALS AND SYSTEMS.

Given the differences in behaviour between 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.

TECHNICAL STUDY

Architecture is a functional art. We need an envelope that protects us from the weather, providing a watertight, durable envelope, which is aesthetically pleasant and enables us to live comfortably. In short, the envelope function involves providing appropriate protection against all external 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, maintaining its integrity 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.

Facing Brick - Traditional Brickwork

Facing bricks are ceramic products, made from clay-like material, whose technical characteristics depend upon 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 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 facing bricks, a ventilated cavity 5 cm wide, thermal insulation of variable thickness and an inner lining with its corresponding finish.

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-coat 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 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.

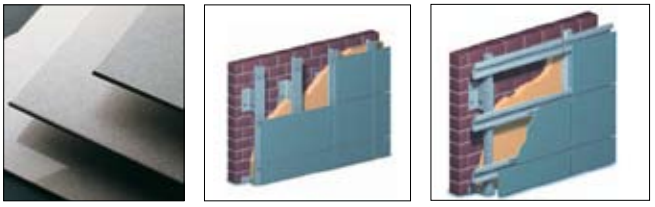
Marble - Panel System

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, that are subjected to high pressures and temperatures. Many types of marbles are available, with various textures (bushhammered, pumiced, sawn, 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 m2, because large formats are difficult to handle due to the weight. According to standard NTE RCP the minimum thickness of the slabs should 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 and hooks which are placed 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.

Porcelain Tile - Visible Clip Systems and Karrat S7



Porcelain tile is a ceramic product, that has a dense body whose main characteristic is its low porosity (even < 0.1%); this provides high levels of strength, and produces very high technical characteristics.

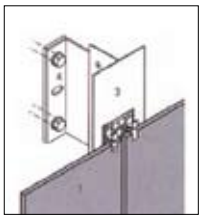
Typical porcelain tiles are pressed into a specific shape, following milling, mixing and spray drying operations. The tile body is then pressed at pressures of 400kgs/Cm^2. The firing process reaches temperatures of 1200°C. These durable dry pressed ceramic tiles should boast water absorption levels that are below 0.5 per cent in accordance with 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 or top courses.

Karrat S7 system: The Karrat S7 system is a ventilated facade system with a substructure that consists of horizontal profiles which are secured to a network of vertical rails. The anchorage consists of an aluminium profile which is adhered to the tile. The anchors slide into grooves in the horizontal rails which secure the tile at the top and bottom. 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.

Extruded Glazed Stoneware - Visible Clip System

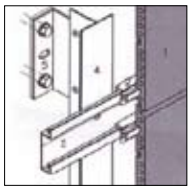


The extruded glazed stoneware tiles used in this system have a resilient clay body. A photocatalysing hydrophilic coating is applied (Hydrotect), which is water and dirt repellent.

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%' which are covered by 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. Note that Hydrotect coatings can be applied to a variety of materials.

Extruded Glazed Stoneware. Keratwin K12 System



Just as in the previous system, the extruded glazed stoneware tiles used in this system have a clay body on which a photocatalysing hydrophilic coating is applied (Hydrotect), 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%'. 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 rails secured to vertical profiles. The anchorage consists of the insertion of four clips in the back part of the tile, secured in a T-shaped groove made during the manufacturing process. These clips are then positioned in the horizontal profile grid which is 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.

Terracotta - Accrodal System

The Accrodal type terracotta tiles are ceramic products, that have a clay body. The materials 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 vertical profiles. The anchorage is based on 4 longitudinal bars made in the rear of the tile during extrusion, which are employed to hang the tiles directly from the horizontal profile grid, which is fastened 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.

Terracotta - Bardeau System

The Bardeau-type terracotta tiles are ceramic products that have a clay-like body. The materials 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%' in accordance with standards ISO 13006 and UNE 67 - 087.

Bardeau system: The Bardeau system is a system for the external cladding of facades. It relies on 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.

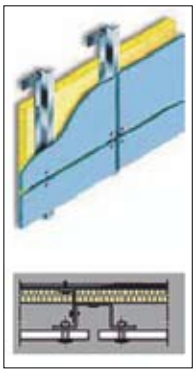
The clips bear the load transmitted by the pieces (own weight and action of the wind) and impart this to the vertical profiles, which transmit it to the decks and wall by means of their corresponding anchorages.

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, prior to 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.

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 adjustable squares. The gap left between the diameter of the hole and the rivet in all the mountings excluding the centre one in the sheet, is characteristic of the system, and this centre rivet is the fixed anchorage point.

Aluminium - Alucobond Screwed Tray System

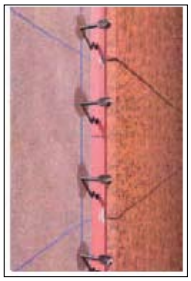
Aluminium is a metal used in the elaboration of composite facade panels of the Alucobond type, formed by two aluminium sheets 0.5 mm thick of 5.005 alloy and PE core. Different types of panels are found with various finishes (thermolacquered, anodised and natural) and colours.

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 rigidity. The sheets are fixed to the substructure by means of stainless steel or aluminium self-blocking bolts located in grooves that allow free expansion in the horizontal direction.

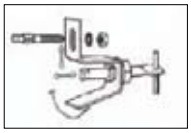
The bottom panels are bolted to the substructure, while the top ones are clipped on. A clip of the same material is set between both elements to leave sufficient room for free expansion of the trays in the vertical direction.

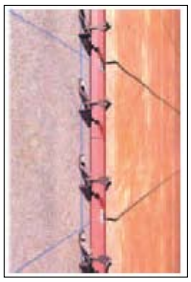
Limestone - Non-adjustable and Adjustable Point Systems

Limestone is a rock with a basic character, consisting mainly of calcium carbonate (CaCO3), 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, sawn, 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.



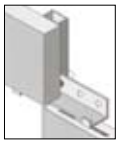


Non-adjustable point system: The fixed point anchorage system is based on the transmission of stresses to the substrate by means of embedded anchorages, set in holes made in the base and retouched with fast-setting mortar. The slabs are fastened by drilling four holes at their edges.

Adjustable 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 three directions that assists in the creation of a plumb, flat surface. The slabs are fastened by drilling four holes at their edges.

Granite - Fix II System With Horizontal Toe

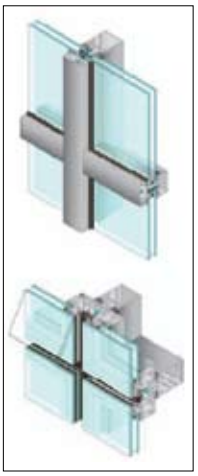
Granite is a crystalline rock, consisting of different quantities of quartz, feldspar and mica, whose main characteristic is its low porosity (below 0.5%); thus, it has a high degree of densification and very high technical characteristics.



There are different types of granites, with various textures (bushhammered, pumiced, sawn, 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 1m2, 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 horizontal toes is a system designed for exterior facade cladding produced 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.

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, which are 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 weight of the envelope and the outer actions it must withstand. The crosspieces are then anchored on these, their 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 weight of the envelope and the outer actions that must be withstood. The crosspieces are then anchored on these, their 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).

Economic Study.

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, (opposite), which include both the cost of the cladding and that of the overall envelope (**table 1**).

However, it is important 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. 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. Refer to **Table 2.**

TABLE 1

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	Thermoclay	PU Ins.	Plaster	Paint	TOTAL
	138.13	31.32	6.42	10.03	4.58	190.48

Limestone - Adjustable Point System

System €/M²	Material	System	Labour	Various		TOTAL
	38.29	26.13	55	7.47		126.89
Envelope €/M²	System	Thermoclay	PU Ins.	Plaster	Paint	TOTAL
	126.89	31.32	6.42	10.03	4.58	179.23

TABLE 2

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

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 an initial table was drawn up (page 106) with the technical characteristics of the materials under study.

We then produced another simplified table to facilitate data comparison. The second table (page 108) details the characteristics of the different studied systems, again considering (although with a lower score) the relevance of the material properties, given their strong relation with the system 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.

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TECHNICAL CHARACTERISTICS OF FACADE MATERIALS

TECHNICAL CHARACTERISTICS	Points	FACING BRICK	SINGLE LAYER	PRESSED PORCELAIN TILE	EXTRUDED GLASS STONEWARE		TERRACOTTA	
				G. PORCEL. TAU	KERAION	KERATWIN	ACCRODAL	BARDEAU
Weight (Kg/m²)	11.5	0.5 - 5.75	1 - 11.5	0.8 - 9.2	0.9 - 10.35	0.8 - 9.2	0.8 - 9.2	0.6 - 6.9
Fire Behaviour	4	1 - 4	1 - 4	1 - 4	1 - 4	1 - 4	1 - 4	1 - 4
Elastic Modulus (N/mm²)	No*	N/A**	N/A**	N/A**	N/A**	N/A**	N/A**	N/A**
Bend Resistance:	17.3	N/A**	0.6 - 10.38	1 - 17.3	0.8 - 13.84	0.8 - 13.84	0.7 - 12.11	0.7 - 12.11
Breaking modulus (N/mm²)	13.3							
Thickness (mm)	3							
Strength (Kg)	1							
Impact R. (cm); Breaking + Strain	8	1 - 8	0.8 - 6.4	0.7 - 5.6	0.7 - 5.6	0.7 - 5.6	0.6 - 4.8	0.8 - 6.4
Tensile R. (N/mm²)	No	N/A**	N/A**	N/A**	N/A**	N/A**	N/A**	N/A**
Compression R. (N/mm²)	17.3	0.8 - 13.84 (1)	N/A**	N/A**	N/A**	N/A**	N/A**	N/A**
Thermal Expansion (°C⁻¹ * 10⁻⁶)	5	1 - 5	0.7 - 3.5	1 - 5	1 - 5	1 - 5	1 - 5	1 - 5
Water behaviour	21.3	0.7 - 14.91	0.7 - 14.91(2)	1 - 21.3	0.9 - 19.17 (3)	0.9 - 19.17 (3)	0.7 - 14.91	0.7 - 14.91
Water absortion (%)	18.8							
Frost R. (%)	2.5							
Property Maintenance (8)	13.5	0.7 - 9.45	0.7 - 9.45	1 - 13.5	0.9 - 12.15	0.9 -12.15	0.8 - 10.8	0.8 - 10.8
Dirt Resistance, Corrosion in saline environment, SO_2 atmosphere, Solar radiation ageing								
OTHER CHARACTERISTICS								
Aesthetic possibilities	10	0.8 - 8	1 -10	1 - 10	1 - 10	1 - 10	0.8 - 8	0.6 - 6
Material homogeneity	9.4	0.8 - 7.52	0.7 - 6.58 (2)	1 - 9.4	1 - 9.4	1 - 9.4	0.9 - 8.46	0.9 - 8.46
TOTAL SCORE	100	**76.47**	**76.72**	**95.3**	**89.51**	**88.36**	**77.28**	**74.58**

TECHNICAL CHARACTERISTICS	Points	STONE (3CM)			FIBER REINFORCED CONCRETE		ALUMINIUM	GLASS
		LIMESTONE	MARBLE	GRANITE	GRC	NATURVEX	ALUCOBOND	DOUBLE (=2500 KG/M³)
Weight (Kg/m²)	11.5	0.6 - 6.9	0.6 - 6.9	0.6 - 6.9	0.7 - 8.05	0.9 - 10.35	1 - 11.5	0.8 - 9.2
Fire Behaviour	4	1 - 4	1 - 4	1 - 4	1 - 4	1 - 4	0.8 - 3.2	1 - 4
Elastic Modulus (N/mm²)	No*	N/A**	N/A**	N/A**	N/A**	N/A**	N/A**	N/A**
Bend Resistance:	17.3	0.7 - 12.11	0.7 - 12.11	0.8 - 13.84	0.65 - 11.245(4)	0.7 - 12.11	0.5 - 8.65	1 - 17.3
Breaking modulus (N/mm²)	13.3							
Thickness (mm)	3							
Strength (Kg)	1							
Impact R. (cm); Breaking + Strain	8	0.6 - 4.8	0.6 - 4.8	0.7 - 5.6	0.7 - 5.6	0.6 - 4.8	0.5 - 4	0.7 - 5.6
Tensile R. (N/mm²)	No	N/A**	N/A**	N/A**	N/A**	N/A**	N/A**	N/A**
Compression R. (N/mm²)	17.3	N/A**	N/A**	N/A**	N/A**	N/A**	N/A**	N/A**
Thermal Expansion (°C⁻¹ * 10⁻⁶)	5	1 - 5	1 - 5	1 - 5	0.7 - 3.5	0.8 - 4	0.6 - 3	1 - 5
Water behaviour	21.3	0.7 - 14.91(6)	0.7 - 14.91 (6)	0.8 17.04 (6)	0.6 - 12.78	0.5 - 10.65	1 - 21.3	1 - 21.3
Water absortion (%)	18.8							
Frost R. (%)	2.5							
Property Maintenance (8)	13.5	0.5 - 6.75	0.5 - 6.75	0.6 - 8.1	0.5 - 6.75	0.5 - 6.75	0.8 - 10.8	1 - 13.5
Dirt Resistance, Corrosion in saline environment, SO_2 atmosphere, Solar radiation ageing								
OTHER CHARACTERISTICS								
Aesthetic possibilities	10	1 - 10	1 - 10	1 - 10	0.8 - 8	0.8 - 8	0.8 - 8	1 - 10
Material homogeneity	9.4	0.6 - 5.64	0.6 -5.64	0.6 -5.64	0.8 - 7.52	1 - 9.4	1 - 9.4	1 - 9.4
TOTAL SCORE	100	**70.11**	**70.11**	**76.12**	**67.45**	**70.06**	**79.85**	**95.3**

	VERY HIGH
	HIGH
	MEDIUM TO HIGH
	MEDIUM
	LOW TO MEDIUM
	LOW
	NO DATA AVAILABLE

NOTE: Evaluation according to material suitability.
** Proper evaluation unavailable due to contraditory information and because it's included in bending resistance.
(1) Points just in facing brick, because is how it works, other systems working in bending stress. PESO: 17,3%.(2) It depends on the ejecution.
(3) Impermeability isn't maintaned where the tile is cut.
(4) Property modification with time.
(5) Manufacturer information.
(6) Heterogeneous properties.

TECHNICAL CHARACTERISTICS OF THE SYSTEMS AND OVERALL COMPARISON

CHARACTERISTICS - SCORE OUT OF 33	points	FACING BRICK	SINGLE LAYER	PRESSED PORCELANIC TILE				TERRACOTTA		LIMESTONE (3CM)	
		Conventional	Continuous covering	Visible Clip	Karrat S7	Visible Clip	Keratwin K12	Accrodal	Bardeau	Non adjustable point	Adjustable Point
Supply & Fix	11	✖ 0.6 - 6.6	✖ 0.6 - 6.6	✔ 1 - 11	✔ 1 - 11	✔ 1 - 11	✔ 1 - 11	Tca. A. (1) 0.7 -7.7	Tca. A. (1) 0.7 - 7.7	✔ - ✖ (2) 0.8 - 8.8	✔ - ✖ (2) 0.8 - 8.8
Industrialised System.	9	✖ 0.8 - 7.2	✖ 0.8 - 7.2	✔ 1 - 9	✔ 1 - 9	✔ 1 - 9	✔ 1 - 9	✔ 1 - 9	✔ 1 - 9	✖ 0.7 - 6.3	✖ 0.7 - 6.3
Flexibility.	6	1 - 6	1 - 6	0.7 - 4.2	0.7 - 4.2	0.7 - 4.2	0.7 - 4.2	0.7 - 4.2	0.7 - 4.2	0.7 - 4.2	0.7 - 4.2
Output.	7	0.6 - 4.2	0.8 - 5.6	1 - 7	1 - 7	1 - 7	1 - 7	1 - 7	1 - 7	0.6 - 4.2	0.7 - 4.9
SUITABILITY - SCORE OUT OF 47											
Tension in the covering material:	15.5	0.6 - 9.3	0.8 - 12.4	0.8 - 12.4	1 - 15.5	0.8 - 12.4	0.9 - 13.95	0.9 - 13.95	0.9 - 13.95	0.5 - 7.75	0.6 - 9.3
Higrothermal movements.											
Easy to ajust											
Machinability.		-	-	✖	REVERSE	✖	✖	✖	✖	SIDE	SIDE
ANCHORAGE TYPE				POINT	CONTINUOUS	POINT	SEMICONTIN.	CONTINUOUS	SEMICONTIN.	POINT	POINT
Anchorage type	4	✔ 0.6 - 2.4	✔ 0.6 - 2.4	✖ 1 - 4	✖ 1 - 4	✖ 1 - 4	✖ 1 - 4	✖ 1 - 4	✖ 1 - 4	✖ 1 - 4	✖ 1 - 4
Ventilated Chamber.	7.5	✔ - ✖ (4) 0.8 - 6	✔ - ✖ (4) 0.8 - 6	✔ 1 - 7.5	✔ 1 - 7.5	✔ 1 - 7.5	✔ 1 - 7.5	✔ 1 - 7.5	✔ 1 - 7.5	✔ 1 - 7.5	✔ 1 - 7.5
Impact fracture risk.	5	1 - 5	0.8 - 4	0.7 - 3.5	0.7 - 3.5	0.7 - 3.5	0.7 - 3.5	0.7 - 3.5	0.8 - 4	0.6 - 3	0.6 - 3
Fail-safe system	12.5	1 - 12.5	0.8 - 10	1 - 12.5	1 - 12.5	1 - 12.5	1 - 12.5	1 - 12.5	0.8 - 10	0.7 - 8.75	0.7 - 8.75
Visible/Hidden System	2.5	👁 0.7 - 1.75	👁 1 - 2.5	👁 0.8 - 2	👁 1 - 2.5	👁 0.8 - 2	👁 1 - 2.5	👁 1 - 2.5	👁 0.6 - 1.5	👁 1 - 2.5	👁 1 - 2.5
MAINTENANCE - SCORE OUT OF 20											
Maintenance:	14.5	11.3	11.3	14.5	14.5	13.75	13.75	12.5	12.5	10.75	10.75
Low Maintenance	2.5	0.8 - 2	0.8 - 2	1 - 2.5	1 - 2.5	1 - 2.5	1 - 2.5	0.8 - 2	0.8 - 2	0.7 - 1.75	0.7 - 1.75
Periodic inspections.	4.5	✖ 0.9 - 4.05	✖ 0.9 - 4.05	✖ 1 - 4.5	✖ 1 - 4.5	✖ 1 - 4.5	✖ 1 - 4.5	✖ 1 - 4.5	✖1 - 4.5	✖ 1 - 4.5	✖ 1 - 4.5
Material ageing.	7.5	0.7 - 5.25	0.7 - 5.25	1 - 7.5	1 - 7.5	0.9 - 6.75	0.9 - 6.75	0.8 - 6	0.8 - 6	0.6 - 4.5	0.6 - 4.5
Easy replacement if broken.	5.5	0.6 - 3.3	0.6 - 3.3	1 - 5.5	1 - 5.5	1 - 5.5	1 - 5.	1 - 5.5	0.9 - 4.95	0.7 - 3.85	0.7 - 3.85
TOTAL SCORE	**100**	**75.55**	**77.3**	**93.1**	**95.7**	**92.35**	**94.4**	**89.85**	**86.3**	**71.6**	**73.85**
Materials only	20	✔ 0.5 - 10	✔ 0.5 - 10	✖ 1 - 20	✖ 1 - 20	✖1 - 20	✖ 1 - 20	✖ 1 - 20	✖ 1 -20	✔ 0.5 - 10	✔ 0.5 - 10
System	65	**33.26** 1 - 65	**19,67**(1) 1 - 65	**116.68** 0.7 - 45.5	**138.13** 0.6 - 39	**114.53** 0.7 - 45.5	**159.96** 0.5 - 32.5	**105** 0.8 - 52	**175** 0.5 - 32.5	**109.38** 0.8 - 52	**126.89** 0.8 - 52
Overall facade closing	65	78.51	80.74	169.03	190.48	166.88	212.3	157.35	227.35	161.37	179.23
Replacement	15	0.8 - 12	0.8 - 12	1 - 15	1 - 15	1 - 15	1 - 15	1 - 15	1 - 15	0.8 - 12	0.8 - 12
TOTAL score	**100**	**87**	**87**	**80.5**	**74**	**80.5**	**67.5**	**87**	**67.5**	**74**	**74**

CHARACTERISTICS - SCORE OUT OF 33	points	Marble (2cm)	Granite (3cm)	Fiber reinforced concrete		Aluminium	Double Glass (ρ=2500 Kg/m3)	
		Traditional panelling	FIX II with horiz. Toe	Glass: Stud-frame	Organic: Riveted sheets	Screwed trays	Visible cover cap	Structural Silicone
Supply & Fix	11	✔ 1 - 11	✔ - ✖ (2) 0.8 - 8.8	✔ 1 - 11	✔ 1 - 11	✔ 1 - 11	✔ 1 - 11	✔ 1 - 11
Industrialised System.	9	✖ 0.7 - 6.3	✔ 1 - 9	✔ 1 - 9	✔ 1 - 9	✔ 1 - 9	✔ 1 - 9	✔ 1 - 9
Flexibility.	6	0.7 - 4.2	0.7 - 4.2	0.5 - 3	1 - 6	0.7 - 4.2	0.5 - 3	0.5 - 3
Output.	7	0.6 - 4.2	1 - 7	1 - 7	1 - 7	1 - 7	1 - 7	1 - 7
SUITABILITY - SCORE OUT OF 47								
Tension in the covering material:	15.5	0.9 - 13.95	0.8 - 12.4	0.7 - 10.85	0.9 - 13.95	0.9 - 13.95	1 - 15.5	1 - 15.5
Higrothermal movements.								
Easy to ajust								
Machinability.		SIDE	SIDE	✖	PERFORATION	BLENDED/PERFOR.	✖	✖
ANCHORAGE TYPE		POINT	SEMICONT.	S.MONOLITIC	POINT	POINT	CONTINUOUS	CONTINUOUS
Anchorage type	4	✔ 0.6 - 2.4	✖ 1 -4	✖ 0.9 - 3.6	✖ 1 - 4	✖ 1 - 4	✖ 0.8 - 3.2	✖ 0.9 - 3.6
Ventilated Chamber.	7.5	✖ 0.7 - 5.25	✔ 1 - 7.5	✖ 0.7 - 5.25	1 - 7.5	1 - 7.5	✖ 0.6 - 4.5	✖ 0.6 - 4.5
Impact fracture risk.	5	0.7 - 3.5	0.7 - 3.5	0.6 - 3	0.5 - 2.5	(3) 0.5 - 2.5	0.7 - 3.5	0.7 - 3.5
Fail-safe system	12.5	0.6 - 7.5	0.8 - 10	1 - 12.5	1 - 12.5	1 - 12.5	0.8 - 10	0.6 - 7.5
Visible/Hidden System	2.5	👁 1 - 2.5	👁 1 - 2.5	👁 1 - 2.5	👁 0.6 - 1.5	👁 1 - 2.5	👁 0.6 - 1.5	👁 1 - 2.5
MAINTENANCE - SCORE OUT OF 20								
Maintenance:	14.5	10	11.25	9.05	5.3	12.75	13.15	12.7
Low maintenance	2.5	0.7 - 1.75	0.9 - 2.25	0.5 - 1.25	0.5 - 1.25	0.9 - 2.25	1 - 2.5	1 - 2.5
Periodic inspections.	4.5	✖ 1 - 4.5	✖ 1 - 4.5	✖ 0.9 - 4.05	✖ 0.9 - 4.05	✖ 1 - 4.5	✔ 0.7 - 3.15	✔ 0.6 - 2.7
Material ageing.	7.5	0.5 - 3.75	0.6 - 4.5	0.5 - 3.75	0	0.8 - 6	1 - 7.5	1 - 7.5
Easy replacement if broken.	5.5	0.8 - 4.4	1 - 5.5	0.5 - 2.75	1 - 5.5	1 - 5.5	1 - 5.5	0.8 - 4.4
TOTAL SCORE	**100**	**75.2**	**85.65**	**79.5**	**85.75**	**92.4**	**86.85**	**84.2**
Materials only	20	✔ 0.5 - 10	✔ 0.5 - 10	✖ 1 - 20	✖ 1 - 20	✖ 1 - 20	✖ 1 - 20	✖ 1 - 20
System	65	**99.71** 0.9 - 58.5	**131,92** (3) 0.6 - 39	**116.11** 0.7 - 45.5	**89.21** 0.95 - 61.75	**135.5** 0.6 - 39	**250-330**	**350-425**
Overall facade closing	65	145,64 (2)	184.27	168.48	140.27	187.35	250-330 0.5 - 32.5	350-425 0.35 - 22.75
Replacement	15	1 - 15	1 - 15	0.6 - 9	1 - 15	1 - 15	0.6 - 9	0.6 - 9
TOTAL score	**100**	**83.5**	**64**	**74.5**	**96.75**	**74**	**61.5**	**51.75**

HIGH	MEDIUM	LOW	👁	VISIBLE	👁	HIDDEN	✔	YES	✖	NO

1) Average cost of the three single layer systems. (2) Thermal isolate material isn't included because it appears in all systems. (3) Average cost sourced from www.alwaystone.com.

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

CONCLUSIONS.

According to the comparative study conducted, the materials which obtained the highest score are Porcelain Tile and glass, due to their high technical characteristics and the preservation of their integrity, which largely results from their high porosity values. Other high scoring products include glazed ceramics because the glaze facilitates cleaning, preventing water absorption which thus increases the materials lifespan. 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 external use, because it enjoys a medium rating in terms of lifespan, 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 as facade material. Finally, the group of materials that obtained the lowest score includes limestones, marbles and fibre-reinforced concrete: materials characterised by a high degree of aging, that have medium or even low mechanical characteristics. In all of these materials 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 minimised, while simultaneously contributing safety in case of failure. In addition, these initial properties are preserved and enhanced due to the excellent characteristics of porcelain tile. The Keratwin K12 system, has 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 undermines the system's aesthetics and long term integrity: 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 without a ventilated air chamber and, with the exception of the curtain wall, exhibit strong and swift degradation. It is particularly important 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 major drawbacks in regard to thermal comfort, need for periodic inspection and 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

Ceramic Museum, Onda, Castellón, Spain features a ceramic tile facade.

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 material integrity, 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, which all degrade within a reasonably short timeframe.

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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