DESIGN AND CONSTRUCTION OF LIGHTWEIGHT FACADE PANELLING WITH CERAMIC TILES

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1. PRESENTATION

The present study deals with the design and construction of a building facade enclosure system, which has been defined as "industrialised, lightweight with ceramic tile veneer". These qualifiers form the basis of the whole process; they are set out below together with other premises and objectives that have contributed to the development:

1.1. CERAMIC USE

The basis was the use of a ceramic material as an outside cladding. As a material with a thousand-year tradition in architectural applications, its favourable characteristics were recognised and used, particularly those crucial to performance in this particular case. These involved: durability, stability of characteristics, low water absorption, low coefficient of thermal expansion, ease of cleaning and maintenance, chemical resistance, ease of industrial production, low purchasing cost, and general acceptance by users and technicians.

1.2. INDUSTRIALISATION OF CONSTRUCTION

We have attempted to approach industrialisation from the widest possible standpoint. The implementation of industrialised techniques in building processes is a need, besides being an irreversible trend. Numerous techniques used at present suffer from a lack of industrialisation, which is customary in other fields of production. Although this situation is changing daily, many building processes are still defined by conditions that belong to past centuries, rather than the dawn of the 21st century.

Industrialisation needs to be understood in accordance with processes that are as organised, rationalised and optimised as possible. Though this is usually identified in architecture with prefabrication, i.e. distancing of the work from the point of installation, industrialisation exhibits more complex characteristics that affect all the operations making up the building construction process. Mechanisation, serialisation, typification and workshop work are the most significant partial aspects involved in this regard.

1.3. ALTERNATIVE TO TRADITIONAL SYSTEMS

Current building envelopes with ceramic finishes are typified by characteristics differing from the elements found at present, whose installation is largely skill-based, performed on site under unreliable conditions, using wet and dirty techniques, producing heavy elements subject to the numerous pathologies to which we are sadly accustomed. We have attempted to offer an alternative to the use of techniques that have remained unchanged for centuries. On the other hand, we realise that the pleasure of users and technicians in using these types of solutions is well founded. It has therefore been attempted to pick out their most favourable aspects: friendly character, ease of installation in every type of environment and adaptability to every type of building.

1.4. LIGHTNESS

The lightness of the components (in building and other fields of production) needs to be judged not only by the advantages afforded but also as a logical end to the process. In certain contexts the goodness of product lightness is unquestioned, however, in building construction the superstition still reigns according to which components need to be heavy.

Lightness (in manufacturing, transport, installation and demolition) undoubtedly favours conducting the work in production and generates economy in efforts and material means. On the other hand, numerous problems relating to distress arise with lightening. These issues are often the result of excessively optimistic approaches and lack of experience in the innovative solutions.

Lightweight structural, compartmentalised envelope systems are endorsed by decades of use in technologically developed countries like the United States and certain

North European countries, where they have been widely implemented, replacing the systems we are used to installing.

Besides the lower weight, the reduction in thickness with regard to usual facades was also a targeted objective, though this was not considered as critical as the former.

1.5. INTEGRAL SYSTEM

An important part in tackling the issue was related to rationalising the whole production process. From the outset, it was sought to make the system an "integral system", i.e. conceived in such a way that production and assembly were part of a co-ordinated scheme, eliminating the successive appearance on site of different trades, so that the whole process would be run by a single organisation. The system is currently being successfully used in numerous building fields with excellent results.

1.6. OWN CHARACTER

After setting out the intentions with regard to the envelope at point in this paper, only a final requirement deserves to be mentioned, with a more abstract character than the others, relatively unrelated to technical demands.

The efforts were continually focussed on producing an enclosure that would manifest its nature with absolute clarity and precision. We are referring to its formal coherence and constructive sincerity. The end appearance of constructive elements needs to match everything that gave rise to them. We are against solutions based on imitating materials and/or techniques that are foreign to these. Unfortunately, such strategies are currently commonplace, owing to the power of the technologies that generate new materials and elements.

In this case, the expression in the facade of certain characteristics was considered essential, such as prefabrication, lightness and the value of ceramic materials.

Finally, it was always considered necessary for the end solution to be a real alternative to the facades that it replaces, especially from the viewpoint of economic cost. As the following pages show, materials and techniques were chosen that did not add important economic burdens, convinced that the attempt would otherwise be useless, considering the current low market price of brick veneer.

2. SYSTEM SOLUTION. COMPLETE DEFINITION AND CONSTRUCTION

After surveying the available types of materials, each system component was correspondingly selected: the following sets out the full list of components for a typical solution. The specific elements and materials used in this proposal are detailed together with the general terms. The items in brackets could be optional in other versions of the same envelope.

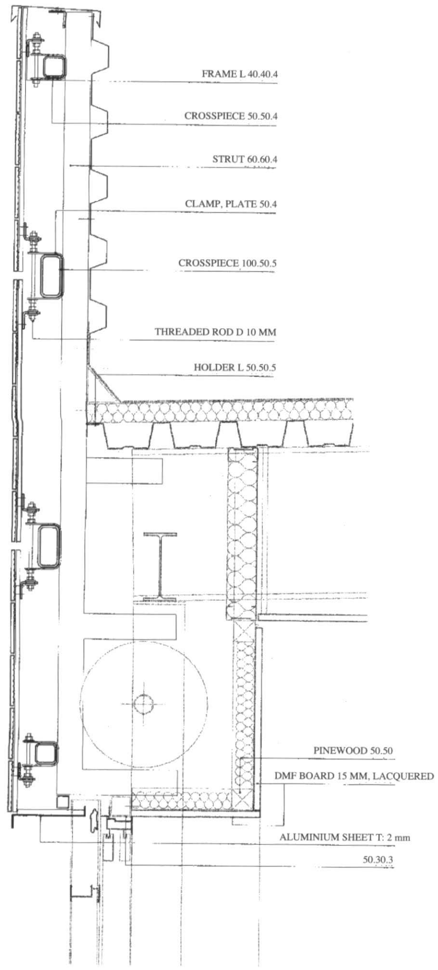


Figure 1. *Standard cross section of the roof parapet.*

VENEER LEAF

PANEL

- Ceramic tile: *glazed stoneware tile, 240 x 125 x 8 mm.*
- Backing: *boards of wood-cement, 10 cm.*
- Adhesive: *cementitious adhesive with resin additives.*
- Grout: *cementitious mastic grout with synthetic additives.*
- (Panel-strengthening structure): *hot-galvanised A42.b steel profiles.*
-(Inter-panel joint sealant): *neutral silicone paste applied in situ.*

UNDERLYING FRAME

-Struts and crosspieces: *hot-galvanised A42.b steel profiles.*
-Underlying frame fastening to the panel: *hot-galvanised steel pieces and bolts.*

CHAMBER

- (Air chamber)
- Thermal insulation: *25 kg/m³ foamed polystyrene sheets.*

INNER LEAF

- Underlying frame: *galvanised steel profiles.*
- Backing: *1.3 mm plasterboard.*

COMPLEMENTARY COMPONENTS

-Trims: *2 mm lacquered aluminium sheets.*

A model of this facade was installed in the extension of the Santa Teresa School, located in the Ermitagaña district of Pamplona. The work was designed and directed by the firm of architects Alonso, Hernández & asociados Arquitectos S.L.

The alterations consisted of a complete new storey for school use on the roof of the existing building that consisted of two storeys. The lightness of the constructive elements was obviously an indispensable requirement for all the constructive systems. The existing face veneer consisted of ceramic brickwork with a metric shape, 4.5 cm thick. Ceramic cladding was set as a requirement by the building owners to harmonise with the existing material in detriment to other solutions that were also light but less friendly. The configuration of the new facade of small-size ceramic tiles, comparable to that of the existing bricks, was considered fundamental for suitable harmony between both materials.

An envelope system of ceramic panels was used in three different versions. Firstly, forming the front on windows and the roof parapet (Figure 1), with a width of 1.80 m along the whole perimeter of the extension. Secondly, covering the full height of the building from grade to crown (up to a total height of 12 metres), as the facade of a newly

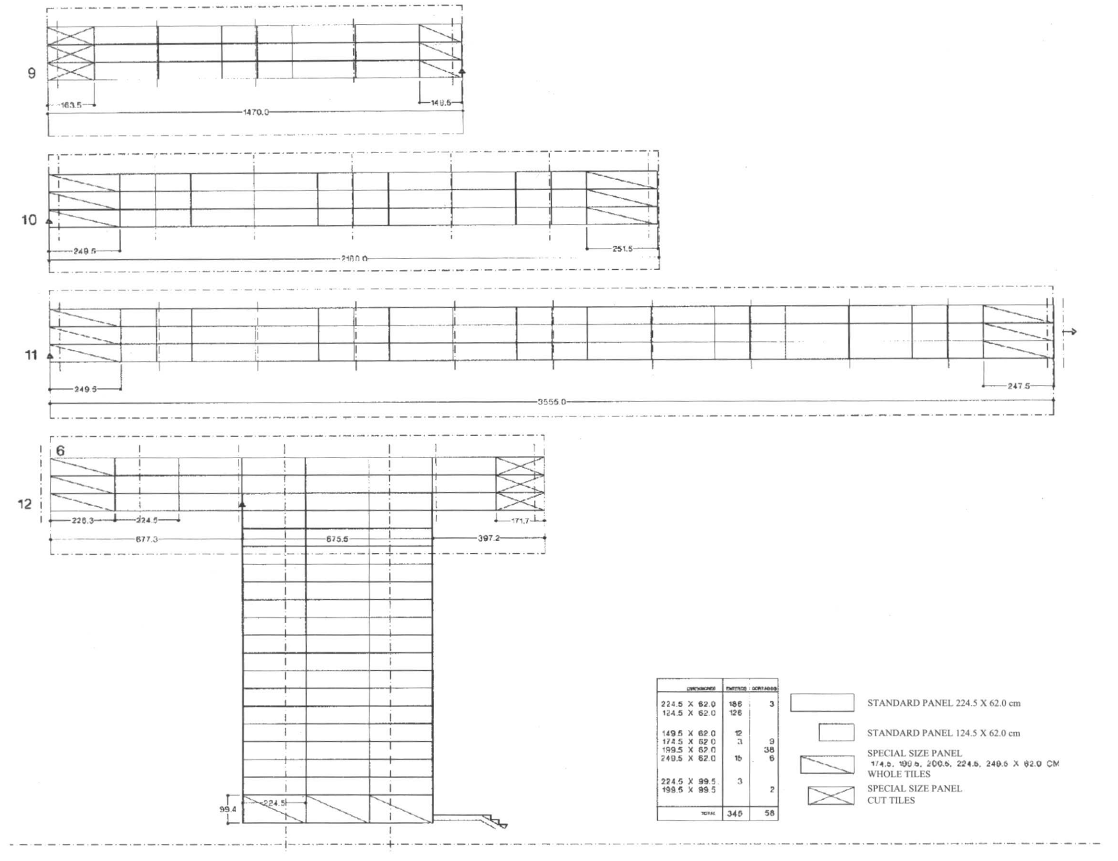


Figure 2. *Panel set out drawing in part of the roof and stairs.*

built emergency stair and lift, and finally backing an existing blind facade.

The following sections set out the selection process of the various components, detailing the most important issues to be solved by the end product.

2.1. FIRST PROPOSAL (MODEL 1)

2.1.A. DESCRIPTION AND JUSTIFICATION OF THE STANDARD ENVELOPE

2.1.A.1. Panel

2.1.A.1.1. Ceramic tiling

From the great variety of ceramic products for cladding walls, we chose a glazed, extruded white stoneware tile, size 245 x 120 x 8 mm. A national product was involved, which was very suitable for outside walls (water absorption of 2-2.5%), of a size and colour assimilable to the brick walls, with a thin lightweight body, and very favourable price/performance ratio.

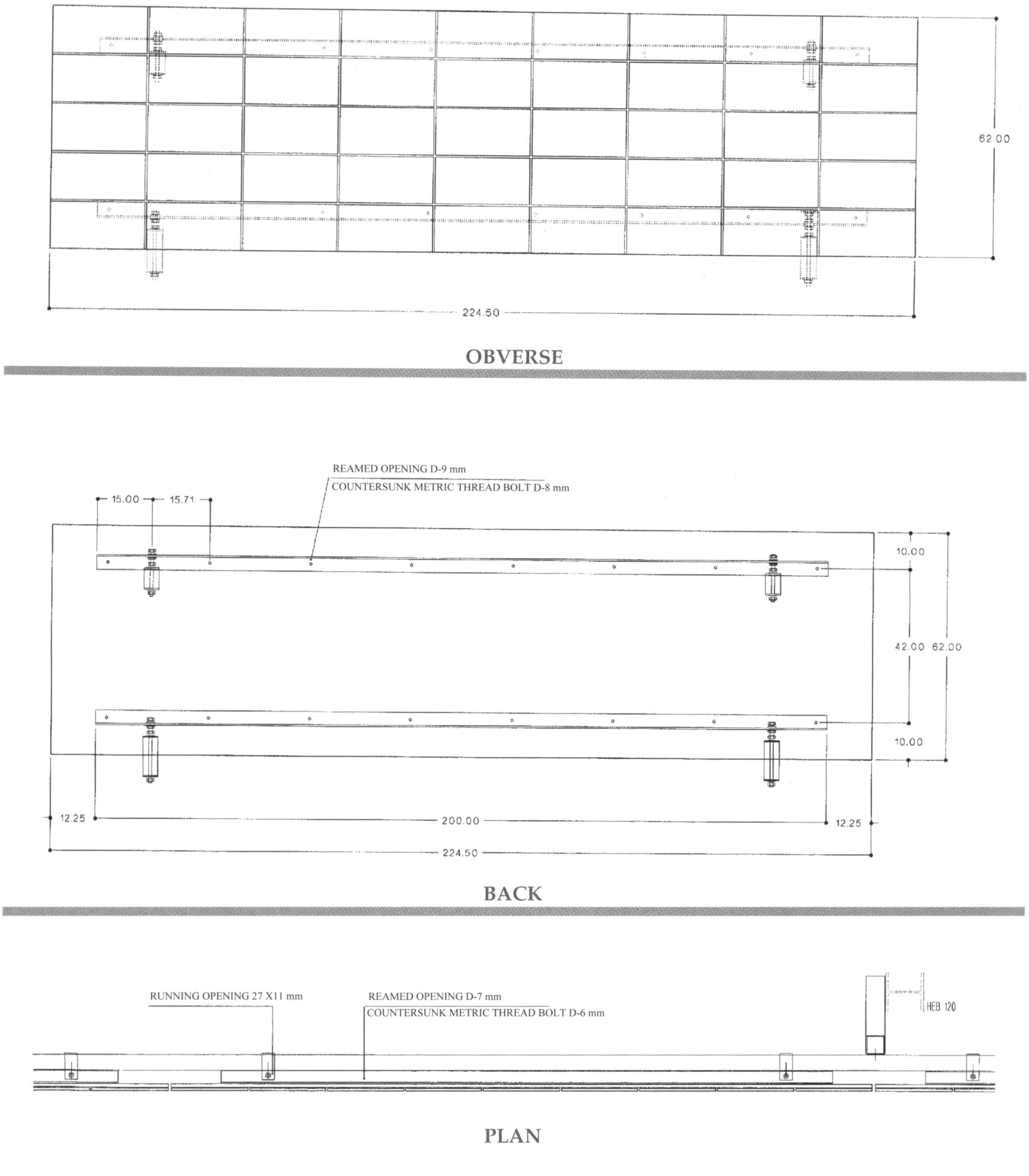


Figure 3. *Obverse, back and plan of the Model 1 panel..*

2.1.A.1.2. Adhesive

The chosen tile was perfectly appropriate for installation by thin-set fixing. Despite the negative panorama presented by the well-known distress phenomena found in fixed cladding, we confided in this case in the characteristics of mortars with additives. A cementitious mortar was used, formulated from Portland cement, silica aggregates and elasticising resins. Its most salient characteristics were as follows: permanent moisture resistance, elasticity and great bonding to ceramic products and various backgrounds.

2.1.A.1.3. Base

Adhered tiling requires a sound flat background. After evaluating different types of tile-fixing bases, 10-mm-thick board was chosen consisting of wooden fibres agglomerated with Portland cement. The material's most important features were the low weight, bending strength (for working with low thicknesses), ease of handling and moderate cost (compared to other higher-performing products). The sheets were delivered at the assembly site already cut in the required size. They were primed with a waterproofing solution prior to fixing the tiles.

Tile fixing was the most skill-based operation. To mitigate this circumstance, it was attempted to rationalise the related operations. A series of workbenches was mounted on which the sheets were placed horizontally. A chain was then organised distributing the following operations: adhesive spreading, tiling, grouting and cleaning. They were all conducted by the usual procedures for the materials and methods used, though it is certainly true that the realisation in a place with good conditions, adequate working stance and systematisation allows obtaining very favourable qualities and output.

2.1.A.1.4. Grouting

The grout is one of the least critical of the set of materials used Characteristics were required similar to those of the adhesive, such as adhesion, water resistance, and elasticity to deform without failure with strain. The product used had a very similar formulation to that of the adhesive: a grout paste made up of cement mortar and special elasticising additives was used. The application was simple and the cost very low.

2.1.A.1.5. Panel-strengthening structure

After establishing the use of a lightweight wood-cement sheeting as tiling background, it was decided to provide it with the necessary reinforcing to withstand the actions involved in mounting and use, besides fitting it with fastening systems. Two profiles were joined to the sheet, parallel to the longitudinal direction, so that their position was suitably adapted to the elements of the underlying frame. Two hot-galvanised, standard L.40.4, steel profiles were used (Figure 3).

The profiles were joined to the sheet by nuts and bolts, a solution decided on for safety's sake compared to other, easier fastening systems such as adhesion or riveting. Galvanised steel lag-bolts were used, with a 6 mm diameter, spacing the anchoring points at centres of about 25 cm.

2.1.A.1.6. Configuration

It was impossible to establish a sufficiently large working module in the existing building to allow adjusting the panels to the vertical lines marked by the structural supports. As it was considered important for the vertical joints to coincide with the external carpentry struts, it was decided to make two different types of panels which, by adequately combining them, provided quite an acceptable adaptation to the heterogeneous modulation found in the building (Figure 2).

The two types of panels designed were similar in every respect, except for their length. In general, the remarks made hereinafter will refer to the larger element, which was more sensitive to certain actions and should be considered the standard panel of the system. The small one was only a circumstantial alteration of the former. The respective dimensions were as follows: 2250 x 625 mm for the standard panel and 1250 x 625 mm for the small panel. The size of the standard panel was considered to match prefabrication cost estimates, whereas the small panels allowed using practically all the sheets supplied by the manufacturer, with minimum cuts and the subsequent economic savings.

It was decided to use a tile bond with a running joint, making it unnecessary to cut the tiles, producing a highly satisfying plastic effect. On the other hand, the tile edges needed to be aligned very carefully. An additional advantage was the possibility of setting the tile sides flush with the board, using whole tiles; it would otherwise have been necessary to cut the tiles before fixing them, which was not considered at all convenient. For the set dimensions, a tile layout was established with a grout joint of 6 mm. This was undoubtedly adequate for the type of product used and yielded a satisfactory aesthetic surface finish.

2.1.A.2. Underlying frame

In the case at issue, it was necessary to have an anchoring system that provided great freedom for the position of the fastenings, so that it was decided to install horizontal crosspieces along the whole facade, fixed to struts welded to the columns of the main structure. The struts were made of 60.60.4 hollow tube profiles.

The size of the crosspieces was decided in such a way as to reduce the number of elements, so that a typical element was designed capable of holding two contiguous rows of panels (Figure 4). The result was a 120.50.5 hollow rectangular profile. A 50.50.5 profile with a smaller cross section was installed at the end lines. Each horizontal line was resolved with continuity, by welding the profiles; control joints for thermal expansion were established by dividing the stretches longer than 30 m.

All the mentioned features were made with hot-galvanised steel profiles, prefabricated in the workshop to the greatest possible extent. After installation, the ties were welded instead of bolted, which would certainly have been better for our purposes: the high cost of bolted ties made this almost prohibitive. The welding points, which affected the zinc coating, were covered on site with two coats of paint with a high zinc content.

2.1.A.3. Panel-frame anchoring

The matter of fastening the panel to the underlying frame was not free of complications, as a series of critical issues coincided. On the one hand, it was necessary to allow each unit to be easily inserted, taking into account the logical order of assembly; moreover, it had to enable performing the required movements for adjusting the planarity and alignment of the edges; finally, after putting the facade into service, the pieces needed to be able to deform without producing unsuitable pressures.

The problem was solved by making a simple fastening consisting of a 50 x 4 mm U-iron, fixed at the ends by screw bolts with a 10 cm diameter and their corresponding nuts. The bolt ends were free so that each allowed anchoring the frames of the two contiguous panels in a vertical direction.

As the plans show (Figure 4), the system allowed each panel to be readily inserted. The fastenings can slide easily along the crosspieces, and can be fixed at any point, by simply tightening the two bolts, with enough freedom to allow adjustment in this direction. The pieces were designed with a certain amplitude to allow moving the bolt vertically to the facade. A possible movement of ±10 mm was estimated to be enough. Finally, the fastening system also needed to allow movement in the vertical direction for the simple fact of moving the nuts that held the panel to the rod up or down. The possibility of adjustments in this direction was determined by the length of this last feature. Ensuring possible movements of ±20 mm was considered sufficient.

Oblong holes were drilled in the reinforcing profiles to enable making minor adjustments on placing the panel, and especially, to favour free movement of the anchoring points during facade life in view of the arising deformations from different sources. A work form was designed, as is usually done with lightweight features of this size, for each panel consisting of the following mechanisms.

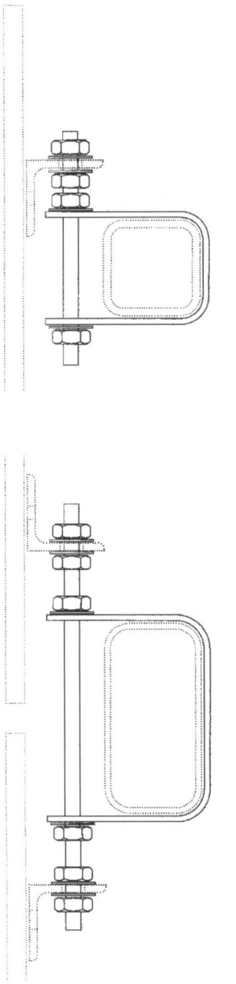


Figure 4. *Underlying frame anchorings to the panel.*

(1). The panels were hung from the top strengthening profile, which was fastened at two points to the underlying frame.

(2). The bottom strengthening profile did not have this supporting function, but acted as a retaining element to the thrust and suction of the wind. This was also fastened at two points to the underlying frame.

(3). Of the four anchorings, only one was designed as a fixed, unmoveable point. In this case the bolt was joined to the profile by two nuts. The top left-hand point, viewing the facade from outside, was always set like this.

(4). The other top point had a sustaining function; it had freedom of horizontal movement. The bolt was fastened to the profile by a single holding nut. The drilled running opening provides for this movement.

(5). The two bottom points can theoretically remain free, with just the rod threaded through the openings. It was preferred to have two bolts that did not remain totally fixed at the top to prevent a possible rise of the panel, which was at all events extremely unlikely.

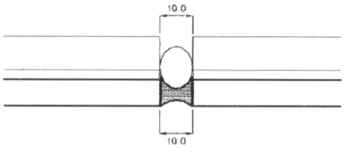


Figure 5. Typical joint

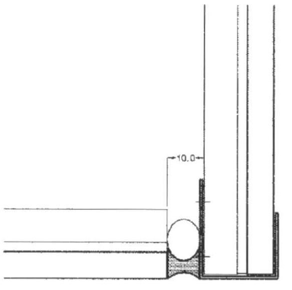


Figure 6. Projecting corner

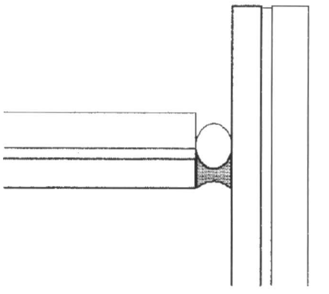


Figure 7. Recessed corner

Each panel was thus free to expand or shrink in both directions without transmitting or suffering additional stresses to or from other features. At the last moment, it was thought of fitting little plastic sleeves to eliminate minor movements and prevent noise. However the idea was discarded because the L-profile size was too small for a sufficiently large opening. In any case, during the period that the facade has been in service, this problem has not arisen.

2.1.A.4. Inter-panel joint sealing

The final state of the panel edges was considered satisfactory with regard to mechanical strength. It was found however, that water in a liquid state could penetrate into the space between the ceramic tiles and the sheet, at the top edge of the panel.

Ventilation by open joints was therefore discarded; the insertion of added protecting elements was also discarded on considering these to be unreliable and difficult to realise. It was decided to apply a sealing paste in situ. A neutral silicone-based paste was chosen, whose mechanical characteristics, bonding and aesthetic appearance were satisfactory. Another of its advantages was the possibility of application without any previous treatment of the base, the only precaution being to work on clean surfaces.

As Figures 5 to 7 show, the application was performed by previously inserting a backing strip made of polyethylene foam. The operation would have been easier if the panel had been slightly thicker, though it was done without any great difficulty.

2.1.A.5. Chamber

After deciding to seal the joints, it was necessary to consider the space between the veneer and the inner face. The absence of air renewal in this chamber could cause many problems relating to hygrothermal conditions. The adequate situation for thermal insulation was close to the inner leaf. Thus the empty space found behind the sheet would have a temperature close to the outside temperature. On the other hand, ceramic tiling has high resistance to water permeability, owing to the surface glaze, which makes inner-outer flow difficult. Under conditions with a high vapour contribution, water vapour concentrations can be expected in the inside air, producing condensation at the colder spots: metal pieces, or any point of the sheet or adhesive layer. The presence of water at any of these points was quite undesirable, in view of the pathologies that could be initiated.

Air renewal was therefore needed in the chamber so that the corresponding openings were arranged at the starting lines and ends of the field lengths, by designing trims for this purpose at these points. The method was judged to be sufficiently effective to ensure good functioning of the system.

2.1.A.5.1. Thermal insulation

The special characteristics of the enclosures built involved certain differences from what could be called standard envelopes. From a theoretical point of view, in the most general type of enclosure, the installation is proposed of an insulating layer of foamed polystyrene as backing to the supporting profiles of the inner leaf in front of the building framework. The use of a material of the V type, (standard UNE 23727 designation) is considered suitable, whose main characteristics are as follows: density = 25 kg/m^3 and thermal conductivity $\lambda = 0.035$ W/m °C. The material may be formulated to obtain fire reaction classification M1, but is usually classified as M4. The minor price difference justifies using the most fire-resistant material, especially as the problem of fire transmission through unbroken chambers in curtain walls is one of their most problematic features. In certain cases the M1 classification can be compulsory according to standard NBE CPI-96 specifications.

2.1.A.6. Trims

The different types of trims used were of the kinds usually found in light enclosures. The crown and base of the different lengths were trimmed with 2-mm-thick, folded kiln-lacquered aluminium sheets. They were fastened with self-screwing watertight plugs fastened to profiles welded to the underlying frame of each enclosure.

2.1.B. BACKING ON THE BRICKWORK

To assess the possibilities of the system with regard to existing facade cladding, a backing was installed to a cored brickwork facade with a non-screeded render. A slightly modified version was used of the Model 1 panels, simply increasing the length of the reinforcing profiles to fit the fastening system of this type of facade. This made it unnecessary to duplicate the struts as each anchoring point served to fix four adjacent panels.

The other elements were different from those belonging to external enclosures and involve a series of fastenings designed to place the panels in the facade at a certain distance to provide a ventilated chamber. The anchoring system consists of the following components:

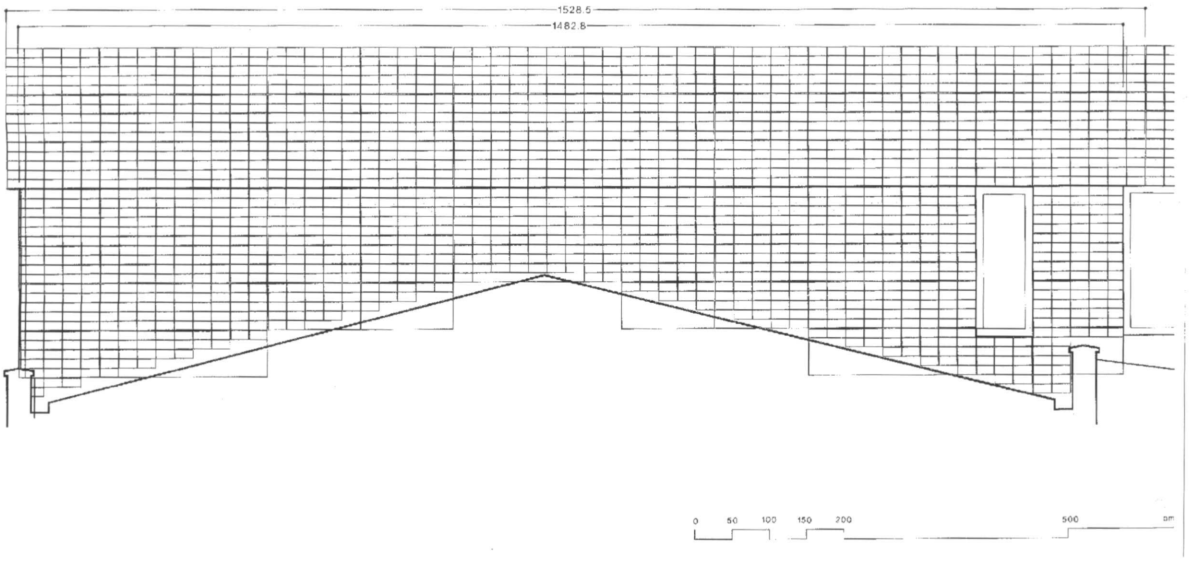


Figure 8. *Elevation of the facade backing.*

(1). "U" type Unistrut uprights, measuring 41 x 41 x 2 mm, galvanised by immersion, fixed to the wall.

(2). Galvanised "hammer-head" lag-bolts, measuring 12 x 30 mm.

(3). Hot-galvanised steel sheet plates, 4 mm thick.

The use of the Unistrut profile with its corresponding bolts answers the need of making eventual vertical adjustments, which can be easily done with these elements. The horizontal adjustments parallel to the facade are possible owing to the running openings drilled in the panel profiles.

Movements perpendicular to the facade are not possible after fastening the struts, so that these need to be fixed in their right position with regard to this dimension. Levelling and plumb of the existing wall are crucial to permitting this operation. No difficulties occurred in this respect, despite the fact that the brickwork did not meet very strict requirements. However, the anchoring fixtures were very simple, yielding important savings in cost and installation.

2.1.C. PATHOLOGICAL PROCESS OF THE FIRST PROPOSAL

During the work on the Model 1 panels, a phenomenon occurred that affected some of the constructed panels, which caused the deterioration of several elements after the facade had been built. The process involved a considerable deformation of the base sheets, which occurred after mounting the strengthening profiles and bonding the tiles.

The deformation basically involved warping of the sheet surface where the movement was not constrained by the reinforcing profiles. Considerable bowing was thus found in a transversal direction along the whole length of the elements (a cross section of the panel at its centre point exhibited a maximum deflection of between 4 and

7 mm, depending on the cases, i.e. a deflection of between 1/60 and 1/110). On the other hand, in the longitudinal direction, deformations occurred at the outer edges, which were not covered by reinforcing profiles. These edges, around 125 mm long bent towards the back of the panel with deflections of up to 4 mm.

About 6 months after the finishing the work, at the start of spring, the two end courses of tiles detached from three of the panels located on the facade of the stair shaft, which faced southeast. It could then be observed that the magnitude of panel warping in this area had increased considerably, causing the tiles to delaminate as a result of the arising stresses. The following sets out a series of reflections aimed at establishing the causes of the process.

- No deformations were observed in the panels until after tiling. They did not occur after priming with an aqueous solution.

- No deformations occurred in all in the lines constrained by the metal profiles, indicating their proper functioning together with the fastening bolts.

- The greatest deformations corresponded to the panels exposed to the sun, suggesting expansion caused by high temperatures could be the cause. However no reversible warping was detected.

- Warping arose in every case, with concave panel deflection inwards, as though the outside fibres of the strong section had lengthened and the inside ones had shortened.

The problem undoubtedly arose owing to the use of wooden fibres in the composition of the base board, which are known to increase in volume as moisture content increases. The reduced expansion values provided by the manufacturer for this cause were obtained after exposing both sides of the sheet to moisture, so that expansion was not considered on exposing only one side to moisture, which produced differential expansion. This explains the absence of deformation during panel priming, which took place simultaneously on both sides.

The only moisture contribution corresponded to the mixing water of the cementitious adhesive. These products are known to contain synthetic resins that lower the amount water needed for mixing and raise water retention during setting. On the other hand, the installed panels had been treated beforehand with a waterproofing primer before tiling. We therefore considered that water absorption by the board would not cause such important deformations. These did not occur however so intensely in the models used in testing beforehand.

Another anomalous circumstance was related to the type of failure found in the base-adhesive-tile assembly. In all the detached tiles, without any exception, hardly any adhesive was adhered to the tile. Practically all the material had remained adhered to the base. This was in clear contradiction to the bonding tests performed on these materials, in which failure invariably occurred as a result of rupture inside the adhesive itself or in the base. Thus, without forgetting the great deformation undergone by these elements, which produced important stresses, some type of anomaly could be considered in the behaviour of the tile-adhesive bond as a complementary cause for the tile delamination. At this point, in view of the good performance of the constraining strengthening profiles, it was decided to solve the problem by designing a different type of strengthening structure that accurately matched the arising stresses in the sheet. The new panel, built on the basis of these considerations was termed Model 2, and is described below.

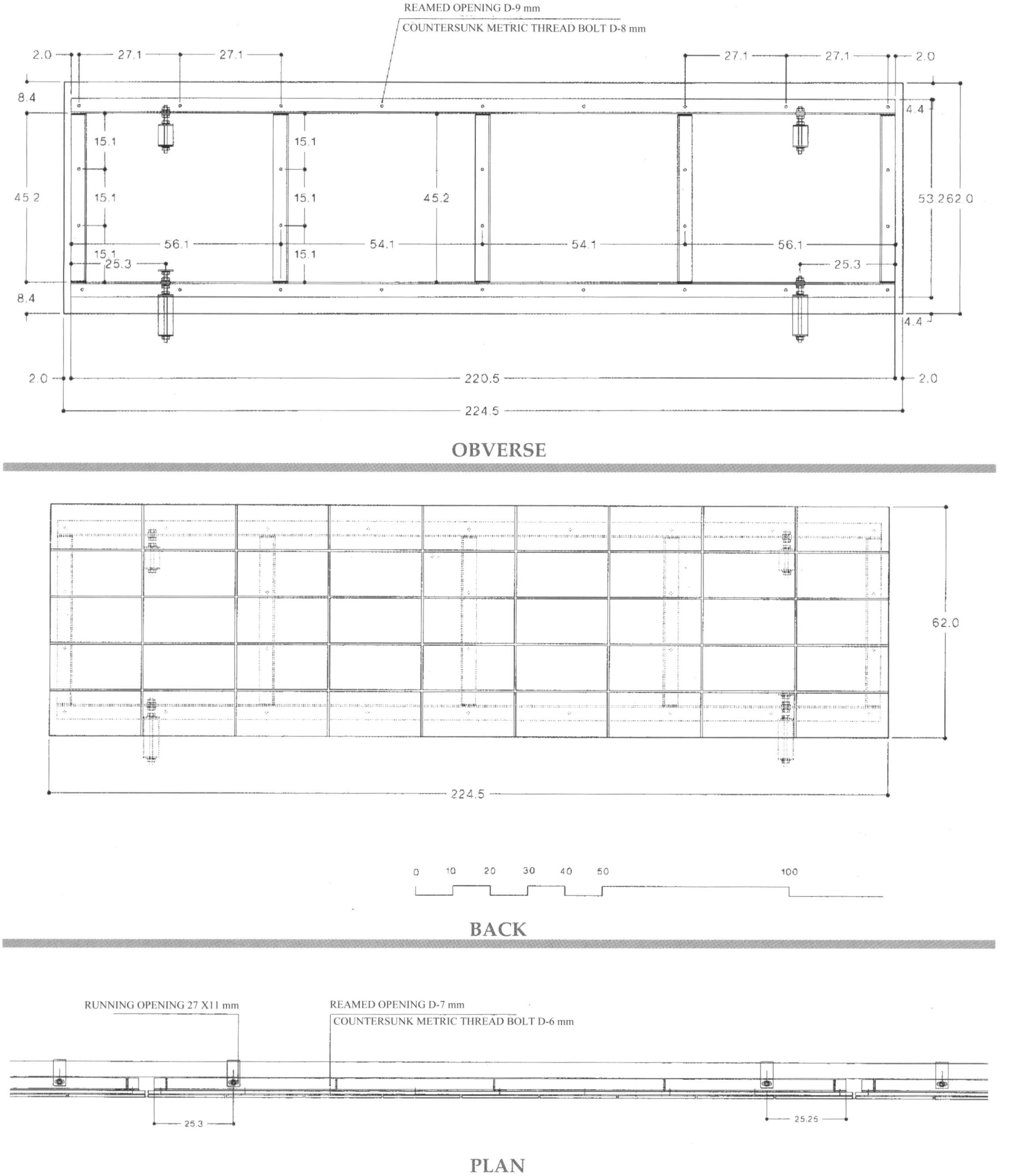


Figure 9. Obverse, back and plan of the Model 2 panel. Definitive proposal.

2.2. SECOND PROPOSAL (MODEL 2)

Except as regards the design of the constraining panel elements and adhesive used, the characteristics of the enclosure were the same as in Model 1.

The possibility of containing the deformations by increasing board thickness was discarded, owing to the weight increase involved. In this sense it was preferred to use a new strengthening system. Independently of the possible ideal design that could be developed, it was necessary on this occasion, for economic reasons and time, to keep the other elements, especially the underlying frame profiles and anchorings, in order to rebuild the facade without altering the other features. The following alterations were thus made to the existing panel (Figure 9).

(1). Turning the longitudinal profiles so that the strengthening profiles at right angles to the board kept their position, while notably reducing the span of the sheet in the transverse direction at both edges.

(2). Extending the profiles to the side edges to limit the span and constrain deformation along the longitudinal axis.

(3). Including new transverse elements, perpendicular to the existing ones, similarly welded to constrain deformation in the transverse direction.

With these operations, the strengthening system became a non-deformable closed frame, joined to the sheet by a much greater number of fixing points. The way of working of the new board was no longer that of a slab supported at two points in two parallel lines, but functioned as a succession of continuous slabs held at their four sides with greater constraints in the length of span. The new solution involved a rise in cost owing to the greater complexity of the frame and longer time required for assembly in fastening this to the board.

Though the use of the same adhesive was considered perfectly feasible, for safety's sake a high-performance adhesive was chosen, involving a two-component polyurethane-based product. The product was easily applied, without any greater difficulties than the former product. The only drawback was its high price, about 10 times that of the first product.

The new panels have performed perfectly during the time they have been installed in the building. The enclosure is assessed to have met the requirements that were initially set.

The following pages present various photographs of the most interesting aspects of the building process and finished work.

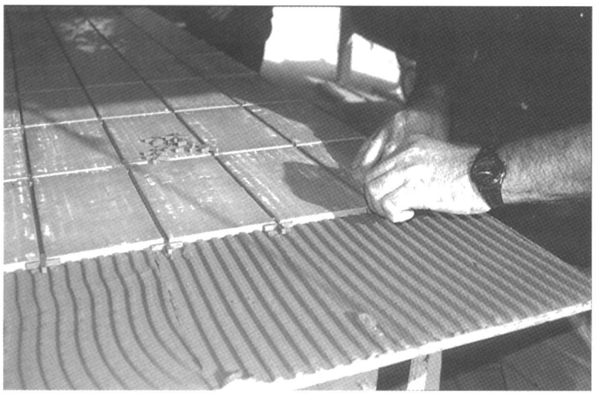


Figure 10. *Panel tiling.*

Figure 11. *Finished panels.*

Figure 12. *Underlying roof parapet structure.*

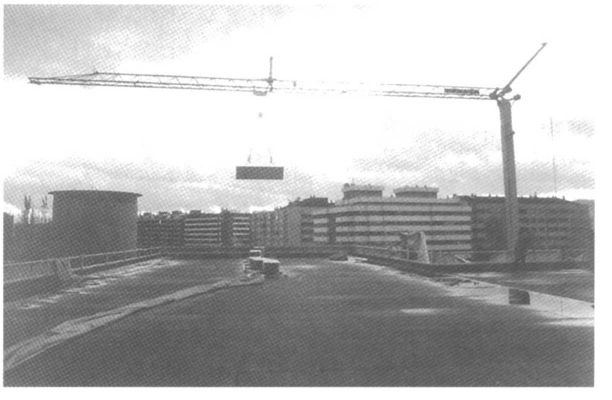


Figure 13. *Hoisting the elements onto the roof.*

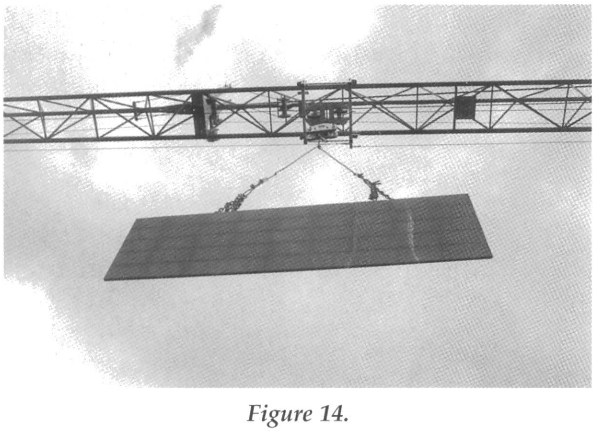


Figure 14.

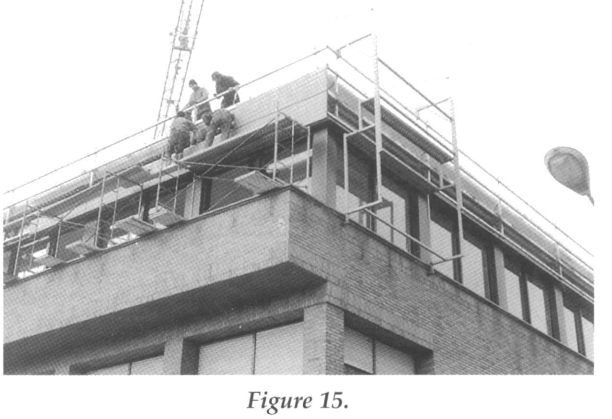


Figure 15.

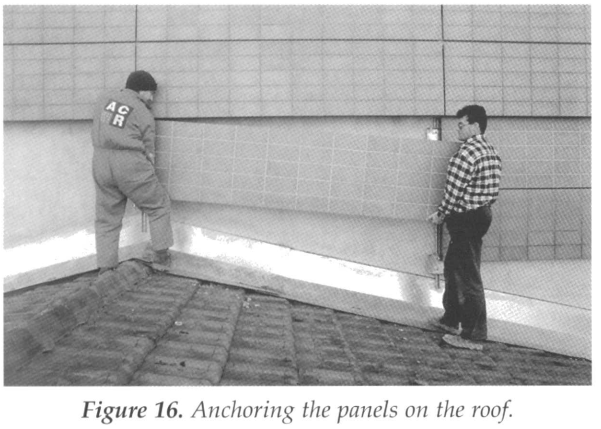


Figure 16. *Anchoring the panels on the roof.*

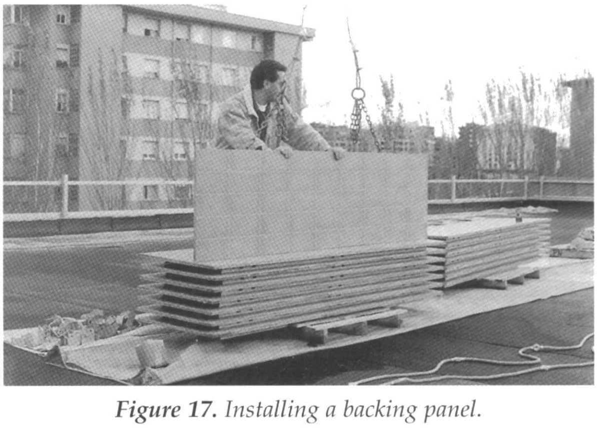


Figure 17. *Installing a backing panel.*

Figure 18.

Figure 19. *Stair outside leaf.*

Figure 20. *Model 2 panel.*

Figure 21. *Installation of Model 2 panels on the stair.*

Figure 22. *Finished work.*

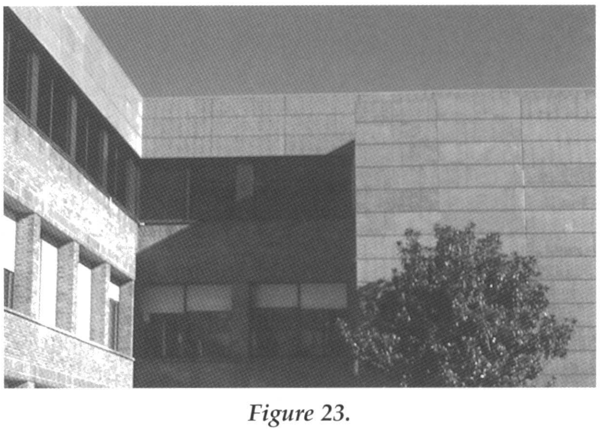


Figure 23.

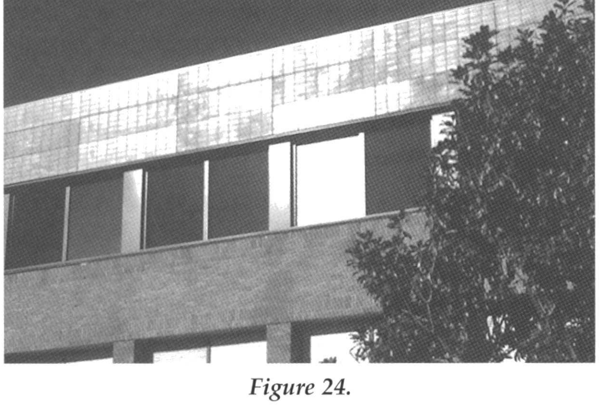


Figure 24.

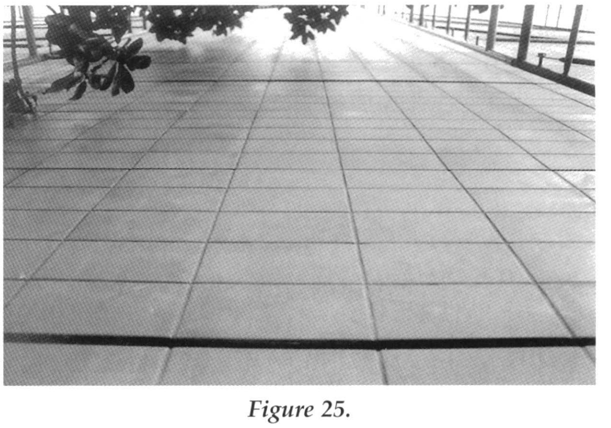


Figure 25.

ANNEX: TESTS FOR THE DETERMINATION OF CHARACTERISTICS

Numerous laboratory test and trials were conducted before installing the panelling described above, to assess the possibilities and real conditions of production and performance of the items involved, on exposure to the main actions that could produce deterioration. The tests were performed in successive stages prior to the definitive construction. Although different materials were used in some cases from the definitive ones, the same type of ceramic tile was used in all the following cases:

A1. GROUP E1: APPLICATION AND INSTALLATION TRIALS

The possibility was evaluated in these first tests of using different materials, by making several scale models of 800 x 400 cm.

E1A y E1B: **Building of a scale model with a wood-cement base, cementitious adhesive with additives and cement-based grout.**

E1C: **Building of a scale model with a base made of wood shavings agglomerated with cement, two-component polyurethane adhesive and cement-based grout.**

A2. GROUP E2: BENDING STRENGTH TESTS OF THE ASSEMBLY (FIGURES A1 AND A2)

Other scale models similar to the former, supported at two points in two continuous parallel lines at the short sides, were subjected to the progressive application of a linear load at right angles to the main plane to evaluate deformation and failure conditions under bending stresses.

E2A y E2B: **Bending on boards of cellulose fibre-reinforced mortar, cementitious adhesive with additives and cement-based grout (Model 1 adhesive).**

E2C y E2D: **Bending on boards of wood-cement, cementitious adhesive with additives and cement-based grout (Model 1 materials).**

E2E: **Bending on boards of wood shavings agglomerated with cement, cementitious adhesive with additives and cement-based grout (Model 1 adhesive).**

The bending strength of the assembly ultimately installed was higher than expected. Failure was found for the two scale models made with the materials on applying a load exceeding 2800 N. The preceding deformations were not excessive and failure of the assembly was neat, with no deterioration in the tiles close to the fracture.

A3. BONDING TESTS ON THE TEST SPECIMENS (FIGURES A3, A4 AND A5)

These were the largest number of laboratory tests, as they indicated the performance of the tile-adhesive-base assembly on exposure to the main external agents. As is well known, there are no standard tests for assessing an enclosure comprising different new generation materials, while the complexity of the phenomena affecting the facade make such an assessment expensive and complicated.

The conditions used for performing the bonding tests are set out in the "UEAtc Technical Guide for the evaluation of ceramic tile adhesives", which correspond quite closely to the most critical actions that the panels could be exposed to, reduced obviously to the scale of a laboratory test specimen. The Technical Guide includes the following four types of tests:

Initial adhesion test without treatment (Point 4.31).

Adhesion test after exposure to heat (Point 4.32).

Adhesion test after exposure to water (Point 4.33).

Adhesion test after exposure to alternate freeze-thaw cycles (Point 4.34).

In our case the following tests were carried out:

Group E3: **Adhesion under all the conditions to boards of cellulose fibre-reinforced mortar, cementitious adhesive with additives and cement-based grout (Model 1 adhesive).**

Group E4: **Adhesion under all the conditions to boards of wood-cement, cementitious adhesive with additives and cement-based grout (Model 1 materials).**

Test E5: **Initial adhesion without treatment to boards of wood-cement without priming and cementitious adhesive (Model 1 materials).**

Test E6: **Initial adhesion without treatment to boards of wood-cement with priming and cementitious adhesive (Model 1 materials).**

Test E7: **Similar to the foregoing test.**

Test E8: **Similar to E5**

Test E9: **Initial adhesion without treatment to boards of asbestos-cement with priming and cementitious adhesive (Model 1 materials).**

Test E10: **Initial adhesion without treatment to boards of wood-cement with priming and polyurethane adhesive (Model 2 adhesive).**

Except for certain isolated cases, the results of these tests were satisfactory, as acceptable adhesion values were found after the different actions, though it was possible to detect a certain drop with regard to the data supplied by the adhesive manufacturers.

On the other hand, on subjecting the assembly consisting of the materials involved in the definitive proposals to the tests, no significant deterioration was found.

A4. ADHESION TESTS ON COMPLETE PANELS (FIGURE A6)

In this case, the bonding was evaluated of the ceramic tiles to the respective bases by pulling whole tiles from the various types of panels, whose composition is detailed below:

E11A y E11B: **Adhesion to two Model 1 panels, made in the laboratory.**

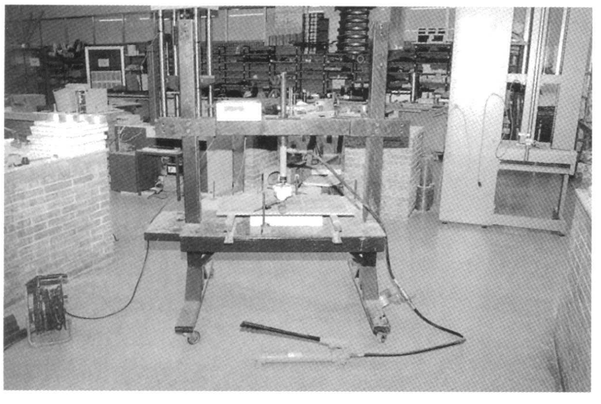
Test E12: **Adhesion to a Model 1 panel, chosen at random on site.**

Test E13: **Adhesion to a Model 2 panel, chosen at random on site.**

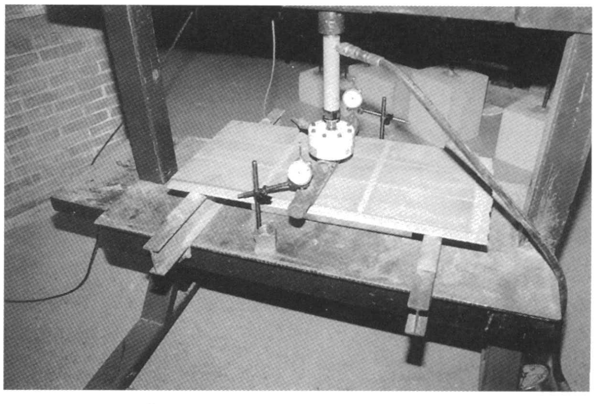
The findings were similar to those of the foregoing bonding tests.

A5. OTHER COMPONENTS

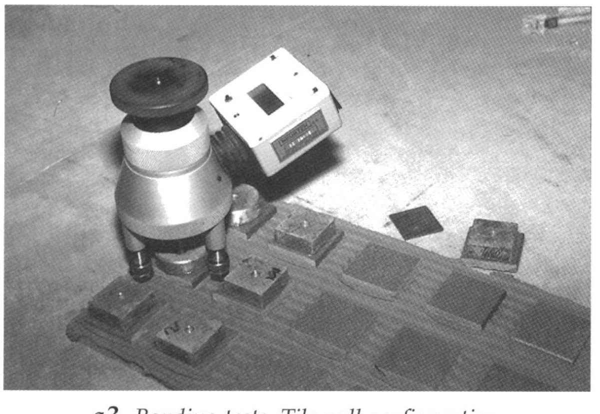
The characteristics of the other system components, such as the underlying frame profiles, sheet strengthening profiles or anchorings, were established by theoretical calculation. Their performance after installing the enclosure was completely satisfactory.



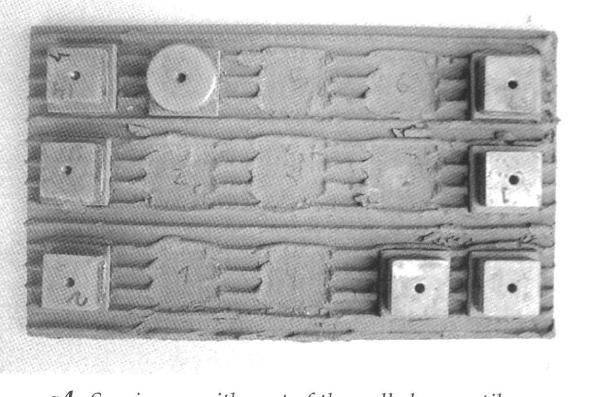
a1. Complete bending strength test configuration.



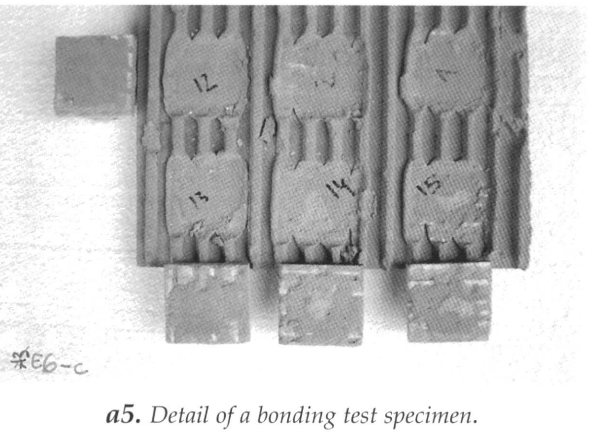
a2. Bending strength test. Detail.



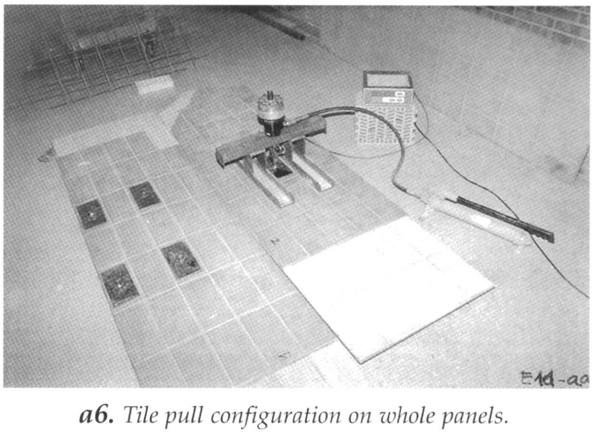
a3. Bonding tests. Tile pull configuration.



a4. Specimens with part of the pulled-away tiles.



a5. Detail of a bonding test specimen.



a6. Tile pull configuration on whole panels.

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