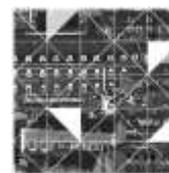


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# CIDADES, Comunidades e Territórios

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## **Total heavy prefabrication: Santo António dos Cavaleiros (SAC) and Quinta do Morgado (QM). Overview of the building process, exterior panel pathologies and a study for their rehabilitation**

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### **Abstract**

Prefabrication is one of the two great methods of industrialized construction that became cost-effective after World War II. The development of such industrialized building techniques was prompted by the great shortage of buildings resulting from the massive destruction of cities, the big demographic explosion and the industrial concentration after World War II (Blachère, 1975).

Traditional construction, which was diffused and disorganized, short of skilled labour, materials and energy, came out ineffective. Most European countries came to the conclusion that housing provision, in terms of quantity, speed of construction and price, could only be solved with the use of industrialized construction.

The use of heavy prefabrication in Portugal began in the mid-1960s, in order to meet the large national deficits (requiring 500,000 new dwellings per year). The first Portuguese building experience with this kind of technology began in 1964, accomplished by the construction company ICESA - Indústria de Construção e Empreendimentos Turísticos. This presentation will explore two significant case studies built by ICESA: Santo António dos Cavaleiros (SAC), a Housing unit of real estate development, with 42 hectares, located in the Lisbon Metropolitan Area, near the Frielas bridge, Loures, about 2.5km away from the main city centre. Around 3000 dwellings were grouped in small-scale buildings (up to 5 floors) and towers (11 floors). They were divided into several categories, according to the organization of the space, floor area, materials and appliances, and typologies of one to four bedrooms per apartment; and, Quinta do Morgado, a Housing unit located in Lisbon, next to the Encarnação neighbourhood, where a total of 1660 dwellings were spread throughout 20 hectares. The planning, design and construction of this housing complex is the result of a bidding process carried out by the Lisbon City Hall (initially for 1140 houses), to tackle the housing problem of the lower classes.

**Keywords:** Total Heavy Prefabrication, Fiorio Process/ICESA, Santo António dos Cavaleiros, Quinta do Morgado, Pathologies, Rehabilitation.

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## 1. The beginnings of industrialised construction/ prefabrication

The concept of industrialised construction was realised in the Industrial Revolution. Due to the general tendency towards industrialisation, this method of construction increased swiftly with the introduction of an organised and mechanical work force, which took place from the beginning of the 18<sup>th</sup> century.

However, until the middle of the 19<sup>th</sup> Century architecture lost the opportunity that industry offered. Architects, generally, didn't know how to take advantage of the available industries. There were, however, some exceptions – one of the most notable being the use of wrought iron and steel used by Nash in the construction of the Royal Brighton Pavilion between 1818 and 1824. Joseph Paxton built Crystal Palace in London in 1851. Prefabricated and standard elements from the foundry were assembled on site in six months (Alonso et al, 1974).

It was at this time that a new material appeared – cement – invented by Joseph Arpin, who patented it in 1824 and gave it the name 'Portland'. However, the discovery of reinforced concrete as a construction material was credited to Monnier in 1867, who patented the manufacture of prefabricated products using a metal mesh covered in cement. Reinforced concrete was created as an industrial product within the spirit of prefabrication. According to Konz, and within this spirit, one of the first and most representative companies was Coighet of Paris, which in 1891 was producing prefabricated beams in reinforced concrete to be used in the construction of the Biarritz Casino (Konz, 1962).

Since the 1920s several architects have tried to solve the housing problems in their countries using industrialised construction as a basis. This process constituted a revolutionary change in architecture itself. It included the cases of Le Corbusier in 1921, Buckminster Fuller in 1927, Marcel Lods and Beaudouin, who created the first prefabricated housing estates in France, at "Cité des Oiseaux" in Bagneuse in 1930, and Gropius and Konrad Wachsmann in 1941 (Alonso et al, 1974).

It was the great shortage of buildings resulting from the massive destruction of cities by bombing, the great demographic explosion and the industrial concentration in cities after the Second World War that made it economically viable and the driving force behind the development of industrialised construction and prefabrication in particular (Blachère, 1975).

Facing the urgent need to solve these building shortages, the European countries reached the conclusion that only industrialised construction processes could resolve them quickly and at low cost. To this end, countries like France allocated 5% of their GDP and used Marshall Plan funding to construct buildings, adopting industrialised technologies, based on reinforced concrete, to set up large construction sites with a large number of buildings.

This process of overcoming major shortages has taken place over two major periods:

– The period of Quantity, from 1947 until the end of 1973 – coinciding with the increase in the cost of oil (the price of a barrel of oil increased fourfold). The dwellings were characterised by little complexity in the organisation of space and small compartment areas. There was also a repetition of buildings, not very interesting formally, and a lack of hygrothermic and acoustic comfort, namely due to the absence of insulation in the exterior reinforced concrete walls.

– The period of Quality, from 1974 onwards – with a reduction of the building shortage, the building site becomes smaller, with fewer dwellings and greater complexity in terms of the organisation of space. The areas of the compartments are larger, with better finishes and equipment, and the users' demands increase in terms of greater hygrothermic and acoustic comfort.

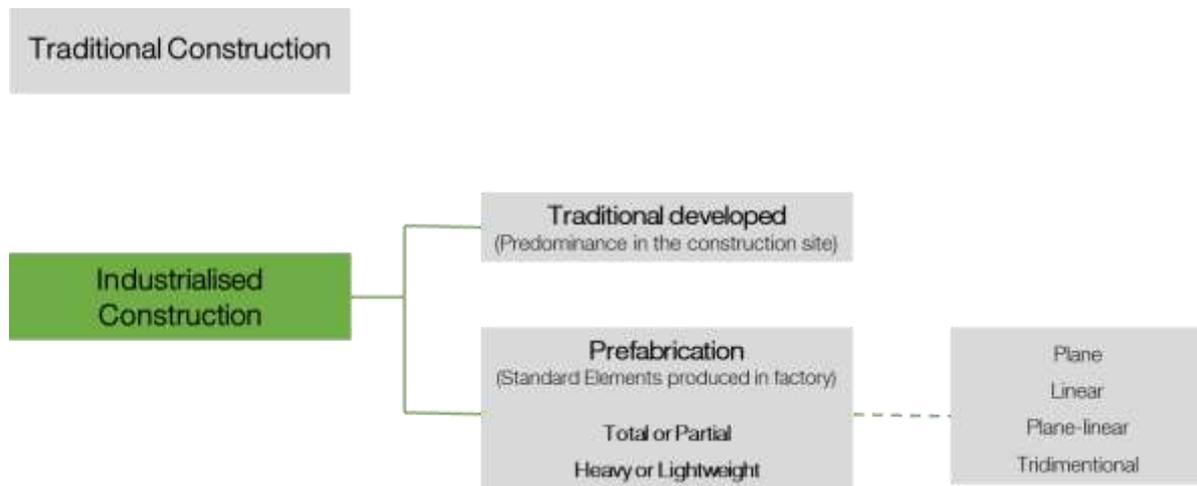
## 2. The building construction

In general, there are two types of building construction:

– Traditional Construction – a slow process, of empirical knowledge passed from craftsmen to apprentices, through the use of traditional materials – walls, vaults and construction elements were built until they could not fall down, and time-tested, long-lasting solutions were found;

– Industrialised Construction – a very rapid evolution, defined by Gerard Blachère as a construction process which replaces the skilled labour of the craftsman with machinery.

**Figure 1. Traditional developed and prefabrication, the 2 major routes of Industrialised Construction**



Industrialised Construction is made possible through 2 major routes:

Traditional developed or rationalised – the predominance of construction work in the building site. Traditional development uses new materials and techniques of moulded concrete for building on site. It uses, at work, a scientific organisation; it demands a complete definition of the project in interdisciplinary terms, preparation of work and methods for buildings; it rationalises and industrialises metallic mould and other equipment for transport and lifting (the concrete stations) and even uses in mixed processes certain prefabricated elements built, sometimes, on site (Reaes Pinto, 1973).

Prefabrication – Prefabrication consisted of the manufacture of those elements which constitute a building in a factory (individual or collective property) which are later transported and erected at the building site. Most of the elements which had traditionally been made at the building site were now sent to factories where they were speedily and efficiently manufactured under shelter from inclement weather, thus reducing the need for specialised workers.

Prefabrication, whether total or partial, light or heavy, has been applied in plane, linear, plane-linear and tridimensional ways (Figures 2 and 3).

**Figure 2. Partial prefabrication of exterior walls – conventional metallic structure**



Source: Author.

**Figure 3. Plane and Plane – Linear Prefabrication**



Source: PAVICENTRO / Author, Aveiro 1998.

Partial prefabrication is used, namely the use of façade panels fixed on conventional reinforced concrete or metallic structures.

### **Total heavy prefabrication in Portugal**

The use of total heavy prefabrication in Portugal began in the mid-1960s, with the aim of helping to solve the country's great deficit of around 500,000 dwellings per year. The first experience of prefabrication with this technology for building construction in Portugal began in 1964 with the construction company ICESA, which applied the French FIORIO process of heavy total prefabrication.

### **ICESA and the FIORIO process**

The FIORIO process is a French system of total heavy prefabrication, utilizing large panels of concrete and brick. This system is one of the oldest, along with the French process CAMUS (1948) and COIGNET (1951), the British process REEMA (1946), BMB (1952), and the Dutch process RBM (1946), all of which are post World War II. The engineering brothers, George and Henri Fiorio, patented their invention in 1951.

With this process more than 100,000 dwellings were completed by 1968 and it was used in France, Spain, Portugal, Germany, Belgium, Austria, Algeria, Venezuela and Iran (Alonso et al, 1974). The FIORIO process was introduced in Portugal in 1964, through a Portuguese company, ICESA, an authorized dealer of the "Société Entreprises de Licence des procédés Fiorio". This Portuguese company had a factory with a production capacity of four dwellings a day and more than 10.000 dwellings were produced in Portugal using this system.

The FIORIO prefabricated construction system consists of the use of large dimension construction elements, one-storey-high wall panels and room sized floor panels which are prefabricated at the factory. These are then mounted on site and interlinked with belts at floor level and reinforced concrete moulded rises "in situ", defining a three-dimensional solid contrived structure. The foundations and the support structure of this type of prefabricated construction are normally undertaken using traditional methods. However, there should be a topping horizontal belt in concrete, to anchor the vertical framework of panels. It can also be undertaken with prefabricated lintels at the foundation anchor, support and joint together stake heads or solid foundation anchors of framework to the rest.

The panels are made up of ceramic blocks laid out in rows, solidified with concrete and supplied with a strengthening framework and suspension.

The manufacture of these panels includes almost all of the construction accessories and finishing, doors and window frames, finishing materials on the faces of the panels, openings for plumbing, tubing and boxes for electrical installations, etc., which allow the definition of each panel. The procedure of loading and unloading during the transportation from the factory to the building site of the prefabricated panels demands the utmost care and the use of specialized equipment. The mounting of the panels on site is done with the help of cranes using appropriate hooks adapted to the different panels.

## ICESA's complex

**Figure 4. Prefabricated decorative panel at the entrance to the company complex**



Source: Author / ICESA 1971.

**Figure 5. ICESA headquarters and entrance**



Source: Author / ICESA 1971.

**Figure 6. ICESA headquarters and entrance**



Source: Author / ICESA 1971.

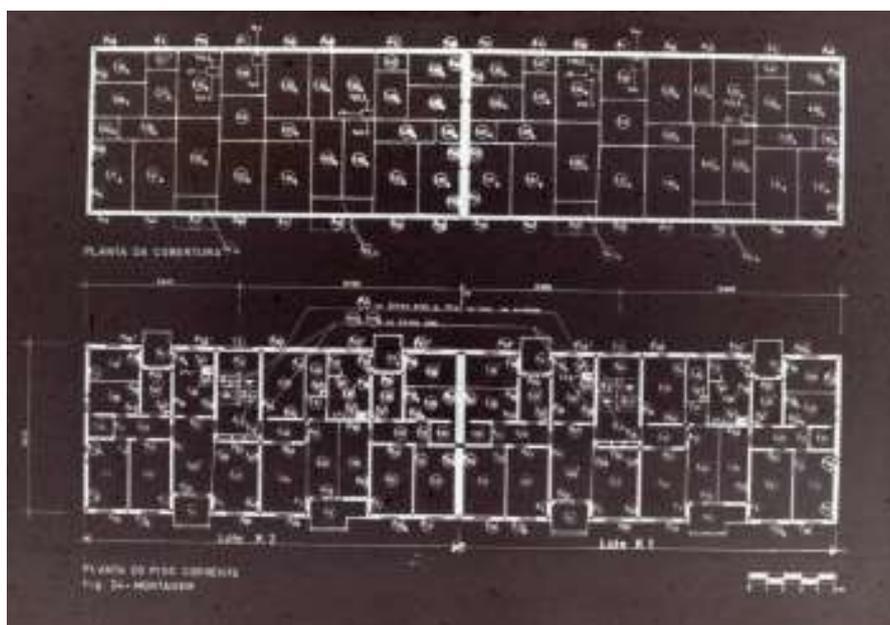
The ICESA complex was composed of the head office building (Administration, Administrative services, Planning and Studies and Projects department), factory, workshops and social services building (canteens, changing rooms, etc.), located in Póvoa de Santa Iria.

**Figure 7. Study and Projects Department**



Source: Author / ICESA.

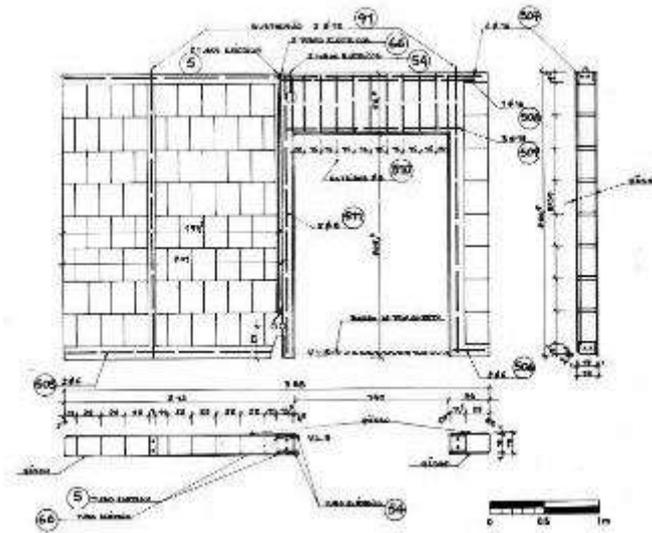
**Figure 8. SAC: Decoupling plans of panels for assembly**



Source: Author / ICESA.



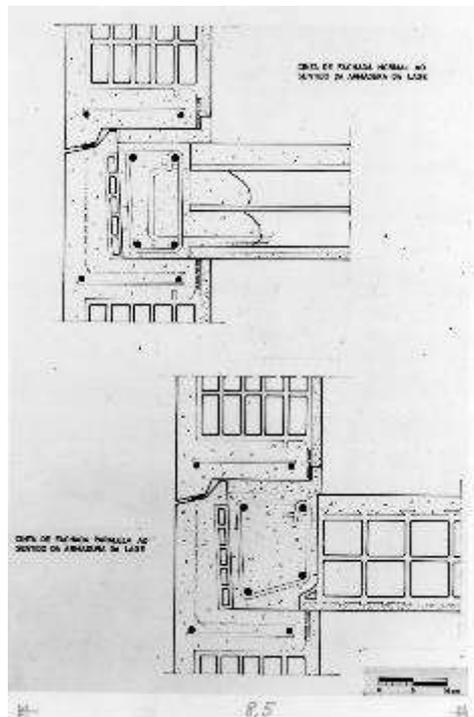
**Figure 11. Resistant Interior panel**



Source: Author / ICESA 1968.

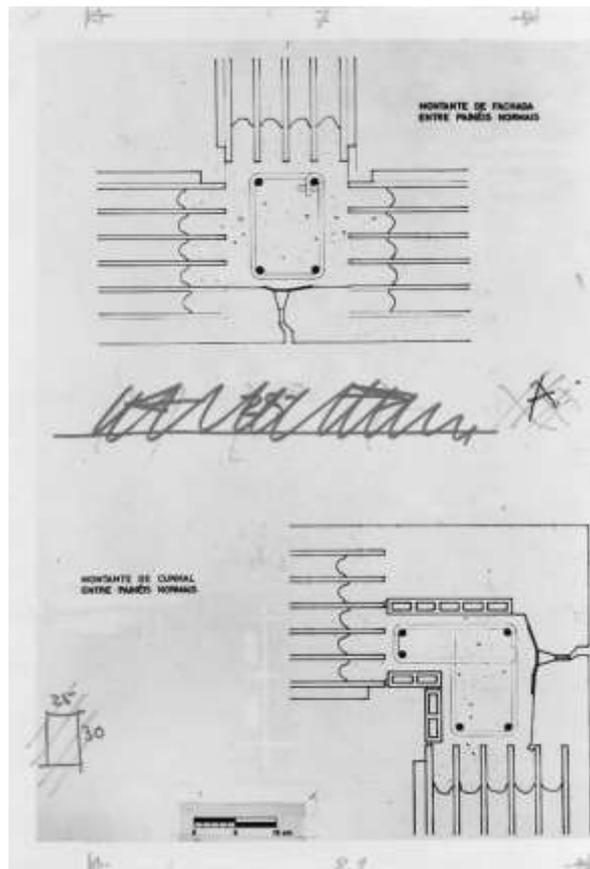
In the construction of buildings, the wall and floor panels are strengthened by a structural network of belts and rises of moulded concrete “in situ” (Figures 12 and 13). The exterior and interior belts differ in their dimensions according to the parallels or perpendiculars and opening floor panels.

**Figure 12. Junction scheme: Belts and rises in reinforced concrete**



Source: Author / ICESA 1968.

**Figure 13. Junction scheme: Belts and rises in reinforced concrete**



Source: Author / ICESA 1968.

## Factory

**Figure 14. Factory: Storage of aggregates for the production of concrete and gypsum and Automating gypsum production station**



Source: Author / ICESA.

**Figure 15. Factory: Storage of aggregates for the production of concrete and gypsum and automating gypsum production station**



Source: Author / ICESA.

**Figure 16. Factory: General view of the factory – metallic horizontal moulds, and lubrication of the bottom of the mould in order to facilitate demoulding**



Source: Author / ICESA.

**Figure 17. Factory: General view of the factory – metallic horizontal moulds, and Lubrication of the bottom of the mould in order to facilitate demoulding**



Source: Author / ICESA.

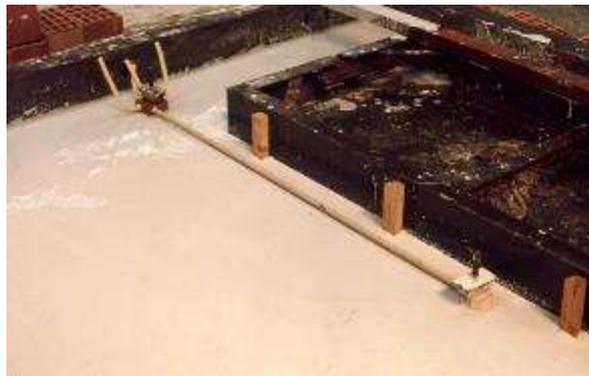
**Figure 18. Gypsum plaster leaking into the mould**



Resistant Interior Panels: the largest number of operations are referred to the manufacture

Source: Author / ICESA 1968.

**Figure 19. Gypsum plaster leaking into the mould**



Resistant Interior Panels: the largest number of operations are referred to the manufacture

Source: Author / ICESA 1968.

**Figure 20. Factory: Concrete leakage and resistant exterior walls**



Source: Author / ICESA 1966.

**Figure 21. Factory: Concrete leakage and resistant exterior walls**



Source: Author / ICESA 1966.

**Figure 22. Resistant interior panels – finishes with ceramic tiles for kitchens**



Source: Author / ICESA 1968.

**Figure 23. Partition wall panels and dividing panels with ceramic tiles as finishing**



Source: Author / ICESA 1968.

**Figure 24. Partition wall panels and dividing panels with ceramic tiles as finishing**



Source: Author / ICESA 1968.

**Figure 25. Hydraulic panel manufacturing mould with a finished partition wall**



Source: Author / ICESA 1968.

**Figure 26. Slab panels and concrete vibration at reinforcement ribs**



Source: Author / ICESA 1968.

**Figure 27. Slab panels and concrete vibration at reinforcement ribs**



Source: Author / ICESA 1968.

**Figure 28. Regularisation of the concrete layer of the slab panel**



Source: Author / ICESA 1968.

**Figure 29. Exterior panels storage areas**



Source: Author / ICESA 1968.

**Figure 30. Exterior panels storage areas**



Source: Author / ICESA 1968.

**Figure 31. Storage area of the exterior panels and prefabricated elements (interior panels) storage yard**



Source: Author / ICESA 1968.

**Figure 32. Storage area of the exterior panels and prefabricated elements (interior panels) storage yard**



Source: Author / ICESA 1968.

**Figure 33. Transport of vertical panels**

Source: Author / ICESA 1968.

### **Case studies: SAC and QM**

This research aims to analyse and study the behaviour of exterior panels of prefabricated buildings, built by the FIORIO process, five decades ago, with particular reference to the perspective of hygrothermic comfort.

These buildings are part of two residential complexes, namely Santo António dos Cavaleiros (SAC) and Quinta do Morgado (QM)

#### **Santo António dos Cavaleiros (SAC)**

This residential complex, comprising approximately 2,500 housing units, is located in the Lisbon Metropolitan Area. The SAC residential unit occupies an area of 42 hectares and has been developed in a calm and wind protected area near Frielas bridge, in the Loures municipality. The N° 8 road in the East-South side marks the border between the actual Loures town and the capital Lisbon. The distance between the residential complex area and the capital border is about 2,5 Km. The land area is developed in a sloped East-South exposition with good conditions for urban development. The complexity and dimension of the urban area led to the design of urban facilities, in accordance to the needs of about 10,000 users.

The residential unit is structured around a common interest area: the Civic Centre. This Centre has a nucleus with commercial areas and it contains a cultural and leisure area.

The 2,500 dwellings are grouped in 5-storey buildings and some 11-storey towers, with different typologies and quality of finishes, with the objective to respond to the various social and economic patterns of the potential users.

**Figure 34. Aerial view of SAC**



Source: Author / ICESA.

**Figure 35. Layout in which the bands of buildings are parallel and spaced equally to allow assembly with the same crane on a single trajectory**



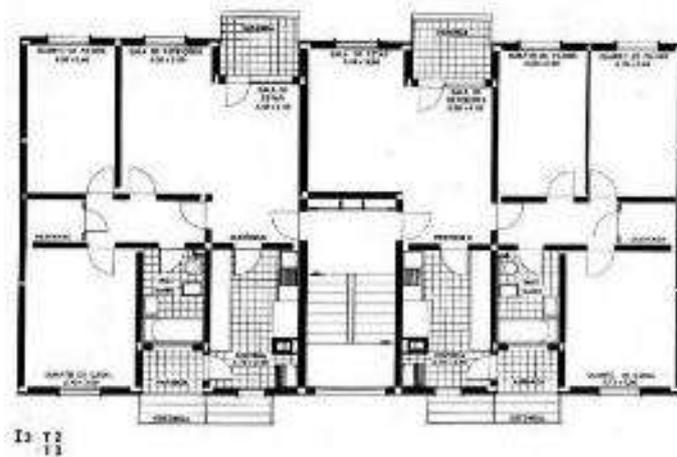
Source: Author / ICESA.

**Figure 36. Implementation of high-rise buildings, without dismantling the cranes. Details of the external arrangements (streets)**



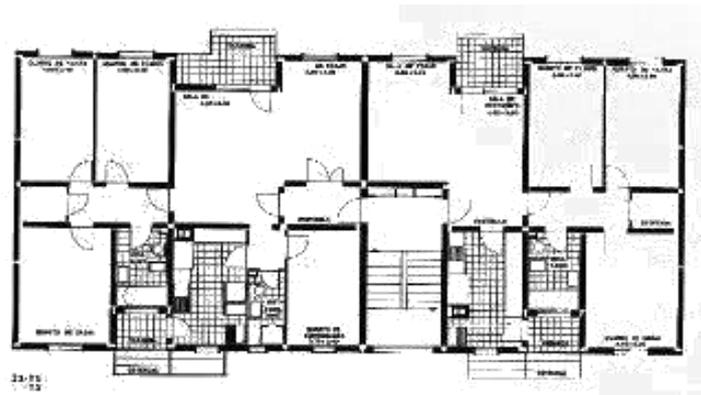
Source: Author / ICESA.

**Figure 37. SAC: Examples of dwellings in the various categories and typologies**



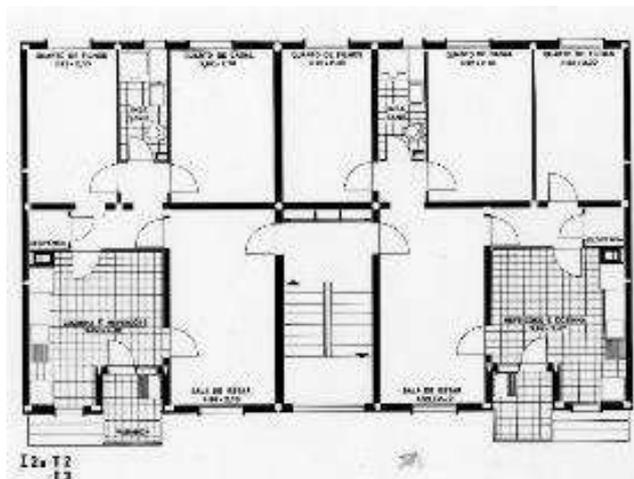
Source: Author / ICESA.

**Figure 38. SAC: Examples of dwellings in the various categories and typologies**



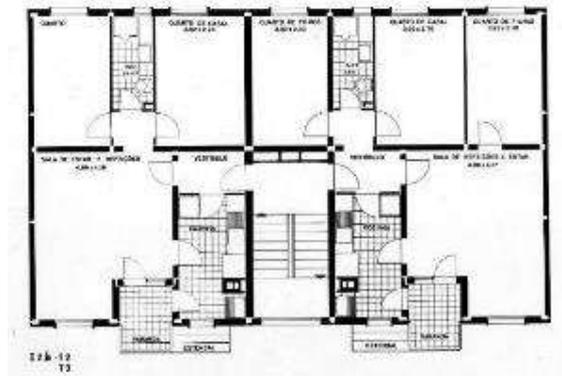
Source: Author / ICESA.

**Figure 39. Examples of dwellings in the various categories and typologies**



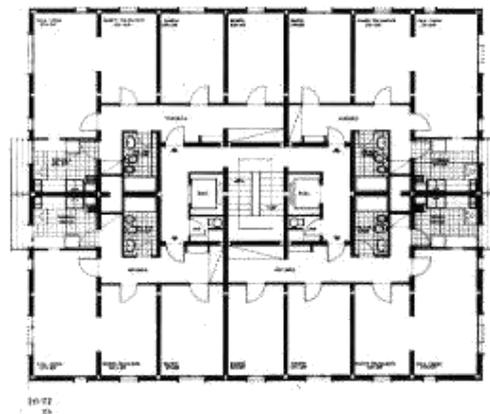
Source: Author / ICESA.

**Figure 40. Examples of dwellings in the various categories and typologies**



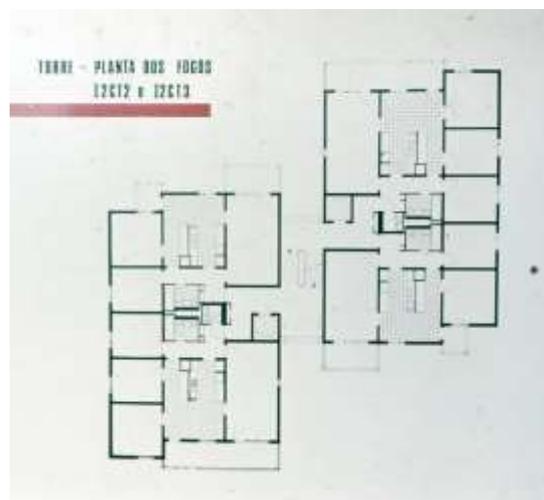
Source: Author / ICESA.

**Figure 41. Examples of the tower dwellings in the various categories and typologies**



Source: Author / ICESA.

**Figure 42. Examples of the tower dwellings in the various categories and typologies**



Source: Author / ICESA.

**Figure 43. Assembly of the panels on site**



Network of electric tubes in the reinforced concrete belts, in the panels connections area (previous to the concreting phase)

Source: Author / ICESA.

**Figure 44. Assembly of the panels on site**



Network of electric tubes in the reinforced concrete belts, in the panels connections area (previous to the concreting phase)

Source: Author / ICESA.

**Figure 45. Assembly of panels on site**



Source: Author / ICESA 1966.

**Figure 46. Assembly of the heavy panels on site and view of the first completed buildings**



Source: Author / ICESA 1967.

**Figure 47. Assembly of the heavy panels on site and view of the first completed buildings**



Source: Author / ICESA 1967.

**Figure 48. Category 2 – Building details**



Source: Author / ICESA 1968.

**Figure 49. Roof protection paving slabs**



Source: Author / ICESA 1968.

**Figure 50. Retaining stone walls without mortar, and streets signage**



Source: Author / ICESA 1968.

**Figure 51. Retaining wall with prefabricated panels of moulded concrete**



Source: Author / ICESA 2000.

**Figure 52. Gabion retaining wall**

Source: Author / ICESA 2000.

**Figure 53. Urban design and tower**

Source: Author / ICESA 1968.

### **Quinta do Morgado (QM)**

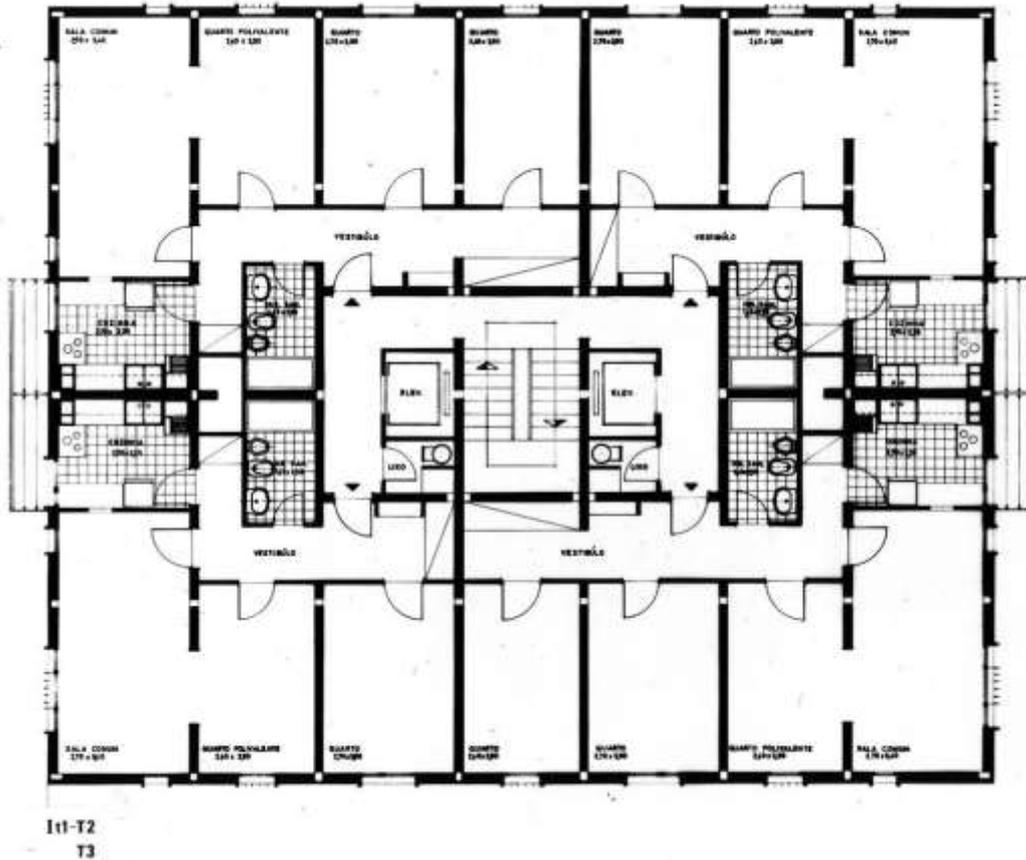
This residential complex is located in Lisbon, near the Encarnação neighbourhood. This urban area occupies about 20 hectares and has been developed in a quiet flat area not far from the Lisbon airport. The A-10 motorway and the Portela residential complex mark the boundaries of the QM complex. The distance between the QM residential area and Av. João XXI, one of the main commercial and financial axis of the capital, ending in Campo Pequeno, is about 4 Km. In terms of commercial, cultural and leisure facilities, the solution adopted is different from the SAC options. QM design has non-concentrated facilities scattered in different areas, according to the users' needs. Other residential areas nearby have facilities such as swimming pools, tennis courts and gymnasia available. QM consists of 1,660 dwellings with similar buildings to the SAC complex residential area and with similar typologies.

Figure 54. Quinta do Morgado



Source: Author / ICESA.

Figure 55. Quinta do Morgado: tower plans



Source: Author / ICESA.

**Figure 56. Quinta do Morgado**

Source: Author / ICESA.

**Figure 57. Quinta do Morgado**

Source: Author / ICESA.

### **The pathologies of the ICESA/FIORIO process**

From a general point of view, the pathological origins of external panels could be the result of:

#### **Conception**

- The under valuation of the thermal resistance of the panels due to incorrect use of materials, both from lack of quality and dimensional problems. The result is water condensation on the interior surface of the exterior panels.

#### **Manufacture**

- The non-squarely mounting of the moulds (horizontal), which creates non-orthogonal panels. This results in non-parallel and non-tolerable joints when mounted, and the leaking of water.

- Incorrect dosage, too much cement and dry mixed fine sand as well as pulverized cement powder on the exterior panels at the finishing point of the manufacture of these panels. This excess of cement gives rise to retractions on the exterior surface of the panels, which results in faults that increase in width over time and weather, allowing water to seep in, giving the panels an unsatisfactory appearance.

- Microfissures due to concrete retraction.

- Direct contact of brick between the outer concrete layer of plaster (3cm thickness) and the interior one (about 1 to 1.5cm) which have given rise to damp patches.
- The absorption of humidity by the panels while still in the factory warehouse, due to prolonged storage (stacked on a sand base); this also gives rise to dirt stains and the degradation of the panel's covering (especially in the case of the plaster).
- Too much oil used when freeing the panel from the mould (at the base of the mould) and on the lower interior surfaces in the plaster, not allowing the plaster any "breathing space", thus causing difficulties in the drying of water in the materials which make up the panels. This also causes difficulty and a lack of adherence of paint when applied to the interior, and also provokes stains in the paintwork due to unequal adherence and absorption of the coats of paint over the plaster.
- Deficient quality control of the manufacture and storage of the panels, resulting in an increase of pathologies and maintenance costs.

### **Transport**

- Bad loading of the panels for transportation, which could result in cracking or even breakage.

### **Assembly**

- Deficient assembly of panels, which even when they are well aligned, can result in irregular joints (non-parallel) and out of line with the determined tolerance, permitting the entrance of humidity.
- Deficient execution of the joints linking two panels in the mounting when the sealing agent has not been compressed correctly. For example, the sealing agent "compriband" only achieved a sealing level when compressed to about 65%. Compression lower than this made the sealing behaviour of this material seriously deficient.
- Deficient fixing of the asphalt band of the sealing of the internal joint of two external panels, which causes water to enter.
- The obstruction of vertical decompression canals of the joints, which impede the draining off of humidity coming from the exterior or building up at the interior joint (condensation water).
- Incorrect placing or pure obstruction of drainpipes, situated at the base of the joints and the links between two panels, which could give rise to infiltration of humidity to the interior.
- Lack of or deficient laying of the "thermal lagging" in the interior, at the joints of two exterior panels, to avoid hygrothermic points and the accumulation of condensation water.
- The falling or dislocation of some panels and their subsequent bad repair.
- The inadequate or inappropriate use of paints or covering materials on the exterior panels at the finishing period.

### **Utilization**

- The over occupation of the space by people, furniture, curtains, etc., without heating or occupation during the day, as well as the lack of internal ventilation (e.g. often windows are kept closed). This stimulates water condensation, mildew and fungi.
- This above-mentioned situation is aggravated due to the misuse of extractor fans in the kitchen, which are not used often enough or are used without the cleaning or substitution of the filters. This results in the appearance of condensation water.

- The two situations mentioned above are sometimes aggravated, in cases where the chimneys' exhaustion is reduced due to the under dimensioning of the "Shunt" type of chimneys.
- The incorrect use of paints on the internal surface of the external walls, which does not let the walls "breathe" sufficiently, leaving humidity within the walls.

**Understanding the pathologies**

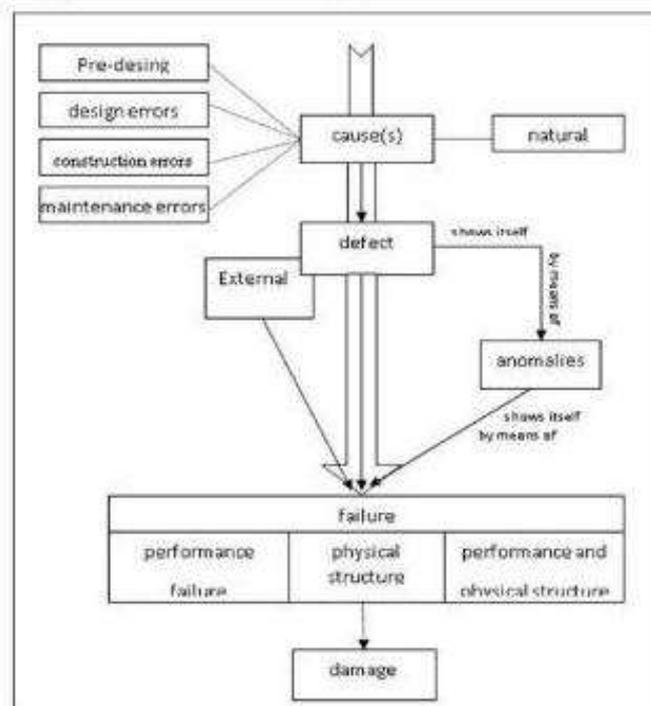
The use of new technologies and new materials was not always tested at an opportune moment. The need to launch a construction process and to construct quickly prompted an increase in anomalies (compared to traditional construction processes, tested with plenty of time) in industrialised construction.

This situation deteriorated further due to improper usage of houses, lack of ventilation and heating and over-occupation. Many aspects may be the subject of building pathology and several relationships exist with other activities in the building field (CIB, 1993).

Generally, the building defects that are considered result mainly from technical aspects. But one should not overlook the fact that the real origins of defects are mainly lack of knowledge, know-how, information and communication (CIB, 1993).

Diagnosis, which is a fundamental part of the building pathology discipline, demands knowledge of the decay process supported by the building components. On the one hand, the pathological decay may begin with one or more errors which might have been committed during different stages of the building process or, on the other hand, errors committed during design or construction. These defects can either remain in a latent form, or manifest themselves by the action of external agents. Interaction between external agents and defects is the necessary condition for the manifestation of the decay as a failure (CIB, 1993), as shown in Figure 58.

**Figure 58. The decay process**



Source: CIB, 1993.

The decay process needs time to develop and it does not immediately cause components to pass from a performance to a failure condition. This is highly relevant to the possibility of planning maintenance strategies with a preventive purpose.

So, if the correct diagnosis of an occurred failure is an important condition to carry out an effective emergency maintenance strategy, the possibility of a correct acknowledgement of anomalies – when the failure has not yet occurred – is fundamental to preventive maintenance planning.

Finally, as a consequence of the failure, the (economic) damage appears at the end of the process (CIB, 1993).

The level of defects inherent to the new construction is fundamentally linked to hygrothermic comfort due to a weak thermal resistance in the exterior walls, and its deficient behaviour towards humidity, fundamentally condensation (BRE, 1991).

According to Oliver (1997), condensation has become a major problem nowadays essentially because of economic and technological change. Increasing energy costs have placed an economic restriction on the amount of heating that occupants can afford, and have encouraged increases in energy efficiency in buildings. Modern building standards have thus aimed at achieving higher insulation and lower natural ventilation levels. Financial pressures have also forced builders to achieve lower building unit costs since the recessions from the late 1970s.

According to Freitas (1995), at the International Symposium on Moisture Problems in Building Walls, the study of moisture migration in building materials is extremely important for the characterization of their behaviour, with regard to its durability, waterproofing, degradation and thermal performances. Condensation is one of the main causes of degradation of materials and construction elements. Among the different mechanisms of humidity fixation, condensation and the physical phenomena of vapour diffusion should be well known in order to design the buildings' envelope correctly. The transfer of moisture, in vapour phase, is caused by various mechanisms, where the building envelope participates in the following ways:

- Transferring humidity by means of the internal air, depending on the building use (occupation and ventilation);
- Transferring humidity through construction elements, as a result of the vapour-pressure-gradient between the internal and external ambient;
- Transferring humidity between the exterior of the element and atmosphere;
- Transferring humidity between the interior of the element and the internal ambient.

**Figure 59. SAC: fissures detected in the external surface of the outside panels**



Source: Author 2000.

**Figure 60. SAC: Micro-fissures in exterior panels**



Source: Author / ICESA 2000.

**Figure 61. QM: Interior humidity coming from exterior panels, caused by the incorrect assembly of the panels or by the lack of compression in the sealants of the panels' joints**



Source: Author / ICESA 2000.

### **Study of the rehabilitation of the exterior existing panels**

Regarding the buildings of these two case studies (SCA and QM), generally without maintenance, some cases of anomalies in the external walls were detected for which solutions were developed.

However, the hypothesis of these solutions should have taken into consideration the location of the pathologies, and the fact that the inhabitants continued to live in their houses in order to increase the efficiency of those solutions to be applied and, if possible, to reduce the costs of those interventions.

Besides the location and the hypothesis to repair the anomalies found, it was necessary to always keep in mind the need to solve the insufficient thermal resistance of the external walls, especially those previously referred to in hygrothermic comfort of the walls.

For this matter, a hypothesis of positioning the thermal insulation material in its exterior is considered.

The option of this hypothesis would result in a general solution of compromise which takes into account the characteristics of the thermal insulation material (its reaction to humidity, in a sense of waterproofing and permeability to steam, its dimensional behaviour, its coefficient of conductivity, its resistance to compression, etc.), the effectiveness of its application and the situation of the inhabitants who must remain in their houses.

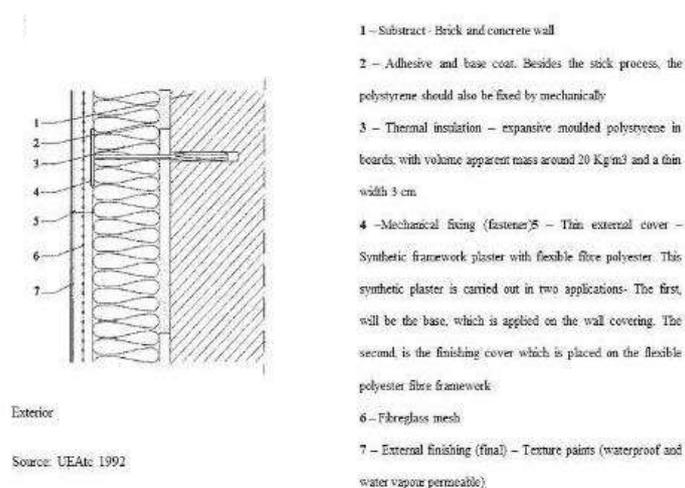
### Solution proposals

It is fundamental to analyse the nature of the pathologies and their location, the technical effectiveness of the solutions' application, the technical conditions and equipment necessary to improve practical corrections in practice. This leads us to consider one solution proposal to the problem of the panels' pathologies.

This solution is, fundamentally, the position of the thermal insulation material in relation to the external panels. The characteristics of the thermal insulation material were studied according to the humidity response, being not only waterproof to the water itself but permeable to the water vapour. Also, this is applicable to the dimensional behaviour, conductivity ratio, compression resistance, application effectiveness and durability.

The proposed solution has the characteristics we now present. This solution is constituted when the thermal insulation material is placed on the outside of the external panel. The mineral reinforced rendering is applied on the thermal insulation. Two layers of synthetic cover with reinforced glass fibre framework or flexible polyester constitutes the "thin" rendering external facing. The texture finishing works are made with cement and resins, with a silicate rendering or with a cover based on EM photo reticulated resins. In the last ten years the appearance and the improvement of these resins has been observed. This resin film hardness and flexibility will be achieved due the solar light influence (CSTB, 1997).

**Figure 62. Summary of the solution developed for the external position of the thermal insulation material on external wall panels**



Source: UEAtc, 1992.

### **Advantages of the Solution**

- The hygrothermic bridge effect is significantly reduced on external walls (in beams and pillars, pavement slab tops, links between internal and external walls). This will increase the effectiveness of the thermal insulation solution.
- Fissuration reduction due to different thermal amplitude on the same day or season. This is a result of the thermal protection of the reinforced structure as well as the masonry, which fulfils the structural framework spans.
- Keeping the interior space without reducing its area.
- Reduction of disturbances on users who continue to live in their homes, due to the structural repairs made on the exterior.
- Improvement to the rainwater penetration on external walls resistance.

### **Disadvantages of Solution**

- Thin coverings in rigid supports are less mechanically resistant to accidental shocks and vandalism compared to conventional ones.
- Compatible requirements of the solution adopted to the building design. The exterior walls' thin increase reclaims an accord with spans and joints between exterior wall panels.
- Spans and joints need finishing profiles and corner reinforcement.
- Weather (temperature, rainfall, etc.), conditions affect the application of this solution.

### **Characterization of the final solution to solve the exterior panel building pathologies**

The final solution for the rehabilitation of the external walls of the SAC and QM buildings will be an external insulation system, totally different from the existing walls and taking into account the counsel of the ETA Guideline on ETICS (EC, 1999). It does not contribute directly to the stability of the wall on which it is installed, but can contribute to its durability by providing enhanced protection from the effects of weathering.

Broadly speaking, the system is constituted by prefabricated thermal insulation products bonded onto the wall, or mechanically fixed using anchors, profiles, special pieces or a combination of adhesive and mechanical fixing.

The thermal insulation product is covered with a thin rendering consisting of one or more layers (applied on site), one of which contains a reinforcement. The rendering is applied directly to the insulating panels without any air gap or disconnecting layer.

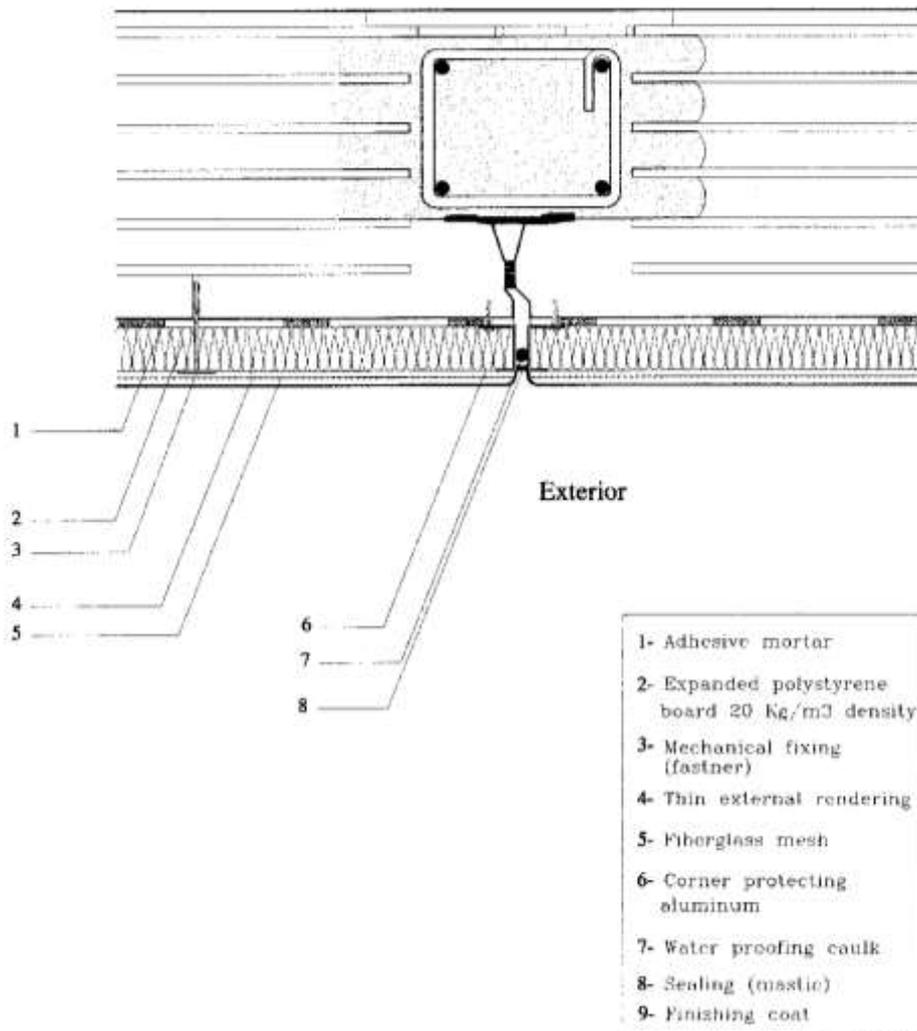
The system includes special fittings (e.g., base profiles, corner profiles, etc.) to connect them to adjacent building structures (apertures, corners, parapets, etc.).

The system is designed to give the wall to which they are applied satisfactory thermal insulation.

It should provide a minimal thermal resistance in excess of 1 m<sup>2</sup>. K/W.

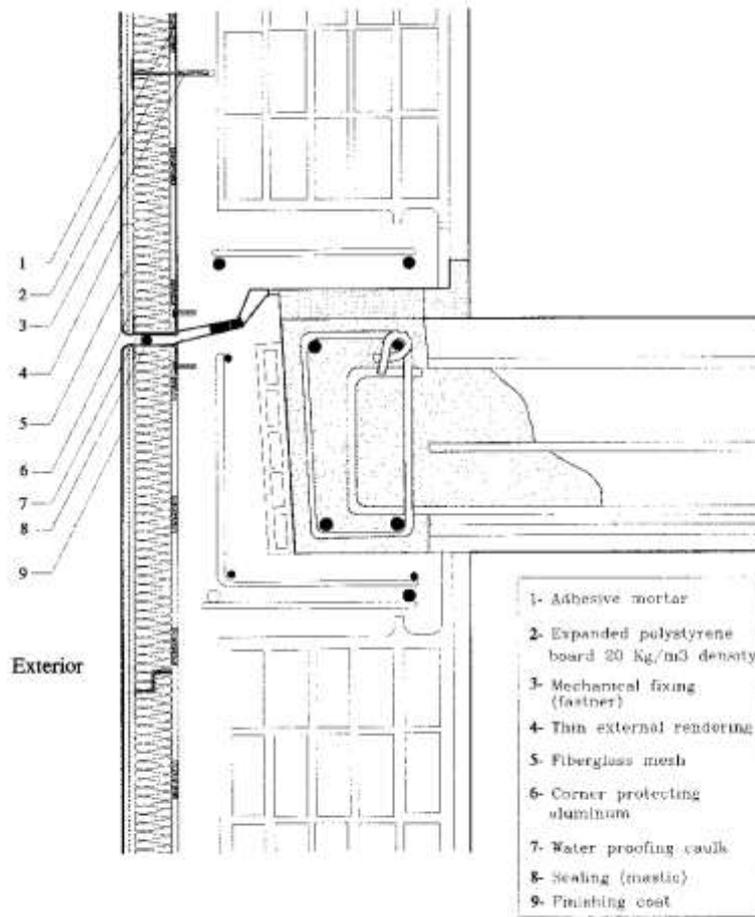
The final solution is presented in figures 63 and 64.

**Figure 63. Rehabilitation of the external walls of the SAC and QM buildings with an external insulation composite system with rendering**



Source: Author.

**Figure 64. Rehabilitation of the external walls of the SAC and QM buildings with an external insulation composite system with rendering**



Source: Author.

**Figure 65. Building work in progress (Science Faculty of Lisbon Building) – The insulation board with adhesive coat applied with points and bands**



Source: Author.

**Figure 66. Building work in progress (Science Faculty of Lisbon Building) – Special fitting profiles to allow an adequate fitting of the pieces and better continuity**



Source: Author.

Bearing in mind the above-mentioned opinions and counsel, a final solution is presented, which is adequate to solve the pathologies of the SAC and QM buildings. This solution aims not only at the hygrothermic rehabilitation of the external walls of these buildings and their resultant energy rehabilitation but also the improvement of the global quality of the buildings so as to prolong their lifecycle.

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