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Business administrator from 1964 at ICESA construction company, specializing in prefabrication at Société Fiorio, in Limoux, France, from 1964 to 1967, and chief designer and production coordinator of a large part of the approximately 10,000 dwellings then built in heavy prefabrication systems.

Elected Correspondent Member of the Portuguese Academy of Fine Arts, he was President of the South Region Council of Delegates of the Order of Architects; President of the College of the Specialty of Construction Work Management, Direction and Supervision; and Commissioner for the evaluation of Architecture graduations of Escola Superior Artística do Porto and Universidade do Minho.

TOTAL HEAVY PREFABRICATION. CASE STUDY: SANTO ANTÓNIO DOS CAVALEIROS AND QUINTA DO MORGADO

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Abstract: 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 18th century.

However, the industrialised construction only became economical viable with 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 and were the driving force behind the development of industrialised construction and prefabrication in particular.

The first experience in Portugal, with this technology was made with the creation of the building construction company ICESA - Indústrias de Construção e Empreendimentos SARL, and the implementation of the French total heavy prefabrication process, named FIORIO, with a production of about 10.000 dwellings.

In buildings that were then about 30 years old, in both case studies Santo António dos Cavaleiros (SAC) e Quinta do Morgado (QM), we found anomalies related to design, manufacture, assembly, use and lack of maintenance, a very common situation in Portugal.

From the two evaluated solutions for the resolution of this type of anomalies, the first one was chosen, due to its advantages - application of the ETICS system, with the thermal insulation placed on the outside of the external walls of the buildings.

However, in a new eventual rehabilitation of the exterior walls of these buildings we would consider the switch of the expanded polyurethane thermal insulation, a material with a lot of fossil fuel incorporated, for renewable materials such as cork, hemp, rock wool or coconut fibre.

Keywords: Industrialised construction; Prefabrication; Exterior walls; ICESA/FIORIO; Anomalies; Rehabilitation.

1. Introduction

This communication refers to research carried out at the end of the 90s of the 20th century, concerning the behavior of the exterior walls of buildings, built in prefabrication, by the construction company ICESA. These buildings, at the time, about 30 years old, are part of two case studies - SAC (own promotion) and QM (public tender, design/construction, for the Lisbon City Council).

This research included aims and objectives. The aim was to analyse and study, fundamentally, the anomalies in the area of hygrothermic comfort of the exterior panels of the SAC's and QM's buildings and to seek solutions to solve faults on external panels. The objectives were presented and they were focused on the proposed solutions to resolve anomalies in the existing building panels.

To detect anomalies in SAC and QM buildings residential area, buildings were studied under the principles of a case study methodology. After making a literature review and to study the state of the art, data from these two case studies were collected supported by quantitative methodologies as direct observation, questionnaires to users, and interviews with experts. This global approach towards anomalies definition and the search of appropriate solutions to resolve them, were based in qualitative framework. This framework links the real world of practice and the thinking world of data treatment and interpretation, assessment and decision. This objective was achieved by the use of soft system methodology.

The contribution to knowledge by way of this research is to develop and improve the quality of the exterior panels of prefabricated buildings, by a hygrothermic rehabilitation using a process of External Thermal Insulation Composite Systems (ETICS), with rendering.

The ETICS system will be developed towards a better effectively, not only in rehabilitated buildings but also in new buildings by the use of new composite materials of less thickness, based on insulation materials, with the best global quality characteristics and productivity

This improvement will contribute towards better behaviour characteristics of the panels from a hygrothermic comfort viewpoint. Thus, the entrance of water from the exterior, the hygrothermic bridges, the formation of the water condensation and heat loss is avoided. The result of this will be an improvement in the residents' quality of life, a reduction in energy consumption and maintenance costs, as well as an increase in the life cycle of the buildings.

2. Development

2.1 - Origins of the industrialisation of 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 18th century.

However, until the mid-nineteenth century, not all architects knew how to use the new materials and technologies that industrialization offered them, with some exceptions that, due to their importance, deserve to be mentioned, such as the use of wrought and steel used by Nash in the construction of the Royal Brighton Pavilion between 1818 and 1824 and that of de 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).

At the same time a new material, Portland cement, appeared, patented by Aspdin in 1824, which was the basis of a product, using a metal mesh covered in cement, reinforced concrete, was credited to Monnier in 1867, 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, who in 1891 was producing prefabricated beams in reinforced concrete to be used in the construction of the Biarritz Casino (Konz 1962).

Since the 1920's 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. Included are the cases of 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 Wachsman in 1941 (Alonso et al 1974).

After the second Word War, the prefabrication of construction elements as a means to industrialisation had its economic feasibility. The lack of buildings was the main reason for the emergence of new technologies of industrialised construction.

Facing the urgent need to solve the 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 hygrothermal 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 lack of buildings, the building site become 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 hygrothermal and acoustic comfort.

2.2. The Economic Origin of Prefabrication

The great transformation and technological progress, made in the area of building in an industrialised sense has, in a general way, been obtained through scientific, theoretical and experimental development.

However, in certain cases, even though there was some technical viability, it was not possible in economic terms. It was only later, due to the new market conditions, that the process had some practical viability.

This is the case with prefabrication (one of the processes involved in industrialised construction) which arose as a consequence of a motivation based on economic factors rather than on scientific speculation or technical progress for, according to Blâchère (1974), "at every moment, the option of technological solutions is undertaken through strict cost competition" (Alonso et al 1974).

2.3. Reasons for Industrialised Construction Development

The prefabrication of construction elements as a means to industrialisation had its economic feasibility after the Second World War. The lack of buildings was the main reason for the emergence of new technologies of industrialised construction.

In 1947, two years after the end of the Second World War the situation was dramatic.

In France, for example, 420,000 houses had been completely destroyed and 1,500,000 were seriously damaged, which meant 1/5th of 1939's patrimony needed construction (CSTB 1997). In England, in London alone, 5.4 million square metres of commercial and industrialised floor space was destroyed or damaged. In England and Wales about 475,000 houses were destroyed by "Luftwaffe" bombing (Powell 1992).

The demographic explosion after the war was enormous throughout Europe (particularly between 1960 and 1975). The French population increased by more than 7 million inhabitants, almost double the increase between 1975 and 1990 of 4 million (CSTB 1997), and the great industrial concentration gave rise to the migration of population to these centers, worsening the lack of housing problem.

The construction industry was very fragmented and disorganised, and its techniques were very traditional.

At that time, France's productivity capacity was of about 80,000 housing units per year (similar to the year 1928, before the war), which was already an insufficient number to fill the needs. Originally the estimates were for about 470,000 houses per year (Blâchère 1975).

Throughout Europe there was a lack of workers (especially qualified ones), and also a shortage of materials and energy. Countries such as France, England,

Germany, Italy and the Soviet Union, amongst others, reached a consensus to solve this lack of housing in terms of quantity, speed and economy - industrialisation was the only way to solve this crisis.

Industrialised construction developed mainly through two principal methods, which established the housing prices opposing and co-operating with each other - prefabrication and developed traditional (CSTB 1997).

2.4. The Building Construction

In general, there are two types of building construction:

- **Traditional Construction** - a slow evolving 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.

Industrialised Construction has developed in two main ways

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 the scientific organisation of work; 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).

Total Prefabrication in which all building components are produced in the factory and assembled on the building site, Figure 1.



Figure 1 - SAC - Assembly of the panels on site. Source: Reaes Pinto/ICESA 1968

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 of specialised workers.



Figure 2 - Partial prefabrication of exterior walls - conventional metallic structure. Souce: Reaes Pinto.



Figure 3 - Plane - Linear prefabrication Pavicentro - Aveiro. Source: Reaes Pinto/1998.

Prefabrication, whether total or partial, light or heavy, has been applied in plane, linear, plane-linear and tridimensional ways (Figure 2 - 5).



Figure 4 - Plane - Linear Prefabrication Pavicentro - Aveiro. Source: Reaes Pinto/1998.



Figure 5 - Lightweight Partial Prefabrication. Source: Reaes Pinto/1998.

3. 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.

3.1. ICESA and the Fiorio Process



Figure 6 - Catálogo Processo Fiorio.



Figure 7 - Catálogo Processo Fiorio - Factories with licensing FIORIO.



Figure 8 - Catálogo Processo Fiorio - Detail of Fiorio Process licencing FIORIO.

The FIORIO process is a French system of total heavy prefabrication, utilising 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 (Figure 6 - 8).

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 (Figure 5) 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 windows 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.

With this process more than 100,000 dwellings were completed by 1968 and it was used in France, Spain, Portugal, Germany, Belgium, Austria, (Figure 6), and Iran (Alonso et al 1974). The FIORIO process was introduced into Portugal in 1964, through a Portuguese company, ICESA, authorized dealer of the "*Société Intreprises 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 production process was carried out at the ICESA Complex (Figures 9 – 11)



Figure 9 - ICESA Headquarter. Source: Reaes Pinto/ICESA 1971. **Figure 10** - Prefabricated decorative panel. Entrance to the company complex. Source: Reaes Pinto/ICESA. **Figure 11** - ICESA Headquarter entrance. Source: Reaes Pinto/ICESA 1972.

Studies and Projects Department - Design Room (Figures 12 – 15)

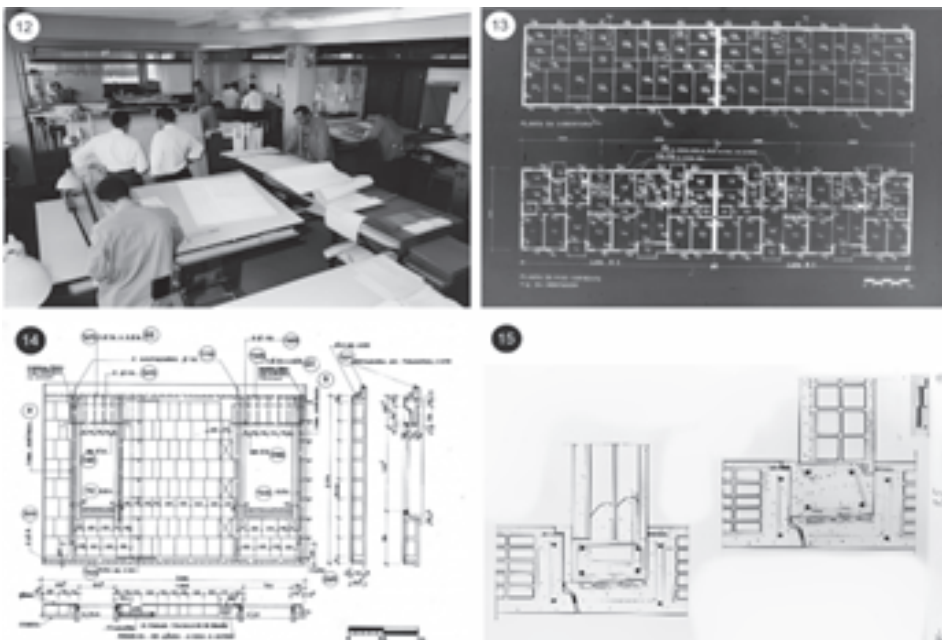


Figure 12 - Design room. Source: Reaes Pinto/ICESA. **Figure 13** - SAC - Decoupling plans of panels for assembly. Source Reaes Pinto/ICESA. **Figure 14** - Facade panel. Source: Reaes Pinto/ICESA 1968. **Figure 15** - Junction scheme - Belts and rises in reinforced concrete. Source: Reaes Pinto/ICESA 1968.

The Factory (Figures 16 – 31)



Figure 16 - Factory complex. Source: reaes Pinto/ICSEA.



Figure 17 - Storage of aggregates for the production of concrete and gypsum.
Source: Reaes Pinto/ICSEA



Figure 18 - Automating concrete production station. Source: Reaes Pinto/ICESA



Figure 19 - Automating gypsum production station. Source: Reaes Pinto/ICESA



Figure 20 - General view of the factory – metallic horizontal moulds. Source: Reaes Pinto/ICESA



Figure 21 - Lubrication of the bottom of the mould in order to facilitate demoulding.
Source: Reaes Pinto/ICESA



Figure 22 - Gypsum Plaster leaking into the mould. Source: Reaes Pinto/ICESA



Figure 23 - Reinforced Resistant Exterior Wall. Source: Reaes Pinto/ICESA 1966



Figure 24 - Concrete Likeage. Source: Reaes Pinto/ICESA 1966



Figure 25 - Resistente Exterior Wall. Source: Reaes Pinto/ICESA 1966



Figure 26 - Resistente Interior Panels. Finishes with ceramic tiles for kitchens.
Source: Reaes Pinto/ICESA 1968



Figure 27 - Partition Walls Panels. Source: Reaes Pinto/ICESA 1968



Figure 28 - Hydraulic Panel manufacturing mould with a finished partition wall. Source: Reaes Pinto/ ICESA 1968



Figure 29 - Slab Panels. Source: Reaes Pinto/ICESA 1968

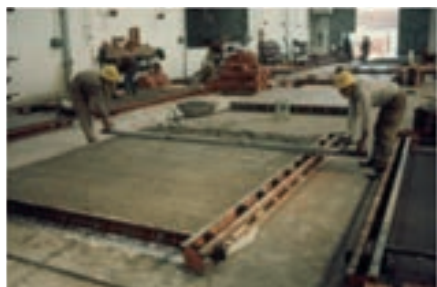


Figure 30 - Regularisation of the concrete layer of the Slab Panel. Source: Reaes Pinto/ICESA 1968



Figure 31 - Lifting. Source: Reaes Pinto/ICESA 1966

Storage Park (Figures 32 – 37)

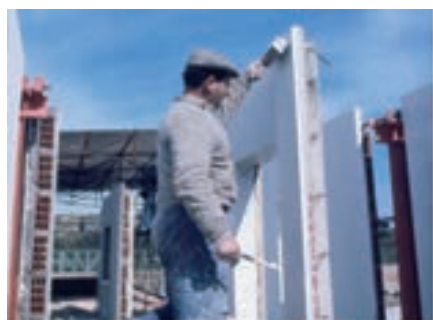


Figure 32 - Regularisation of the concrete layer of the Slab Panel. Source: Reaes Pinto/ICESA 1968



Figure 33 - Lifting. Source: Reaes Pinto/ICESA 1966



Figure 34 - Storage Park Areas – Exterior Panels. Source: Reaes Pinto/ICESA 1968



Figure 35 - Storage Park Areas – Exterior Panels. Source: Reaes Pinto/ICESA 1968



Figure 36 - Storage Park Areas – Interior Panels. Source: Reaes Pinto/ICESA 1968



Figure 37 - Transprot of Slab Panels. Source: Reaes Pinto/ICESA 1968

Construction Site / Case Studies: SAC and QM

Santo António dos Cavaleiros (SAC) – (Figures 38 – 55)

This residential complex is located in Lisbon's metropolitan area comprising of 2,500 housing units. 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 distance between the residential complex area and the Lisbon border is about 2,5 Km. The land area is developed in a sloped Nascent – South exposition with good conditions to the urban development location. The complexity and dimension of the urban area leads to a complementary urban equipment design, in accordance to about 10,000 user's needs.

The 2500 dwellings are grouped in 5 storey buildings and some 11 storey towers, with different typologies and levels of finishing, the objective of which is to respond to the social and economic user's patterns.



Figure 38 - Aerial view of the SAC. Source: Reaes Pinto/ICESA

Figure 39 - Partial view of the SAC. Source: Reaes Pinto/ICESA



Figure 40 - Layout in which the bands of buildings are parallel and spaced equally to allow assembly with the same crane on a single trajectory. Source: Reaes Pinto/ICESA

Figure 41 - Implementation of high-rise buildings, without dismantling the cranes. Details of the external arrangements (streets). Source: Reaes Pinto/ICESA

Structure of the Buildings

The ICESA dwelling projects were studied in several categories and types. The category is expressed by the greater or lesser complexity of the organization of space in the dwellings, by the development of the respective areas and finishings, and the type by the number of bedrooms.

Thus, we tried to structure a basic dwelling within each category and maintain this structure in the passage from a T1 to T2 T3 and T4 type dwelling, so that it was possible to use common panels and common areas - water areas and bedrooms - as many times as possible, applying, on the other hand, the same construction details within the same category and whenever possible in different categories, as can be seen in the examples presented.

This growth of dwellings within the same category, according to the same structure and repetition, is achieved through a compromise between the organization of space, the respective load-bearing wall structure and the areas, which are conditioned by the economic nature of the project.

In the initial projects, the dwellings are grouped in two types of fire per building floor, constituting a non-symmetrical set: example T2 + T3 and T3 + T4. This asymmetry in the grouping of the two dwellings has the inconvenience that the percentage of the repetition of the T3 dwelling is always much higher than the other T2 and T4, but on the other hand it has advantages in the organization of the parietal structure. We have, however, fire types in which their grouping is symmetrical and in which the percentages of the fires are independent of each other.

In the last projects we have achieved a more regular wall structure and partitions, in order to reduce as much as possible, the number of different panels.

Category and Typology of Buildings



Figure 42 - SAC - Category I3 - Typology T2/T3. Source: Reaes Pinto/ICESA

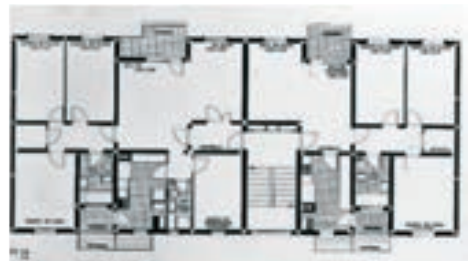


Figure 43 - SAC - Category I3 - Typology T4/T3. Source: Reaes Pinto/ICESA



Figure 44 - SAC - Category I2a - Typology T2/T3. Source: Reaes Pinto/ICESA



Figure 45 - SAC - Category I2b - Typology T2/T3. Source: Reaes Pinto/ICESA

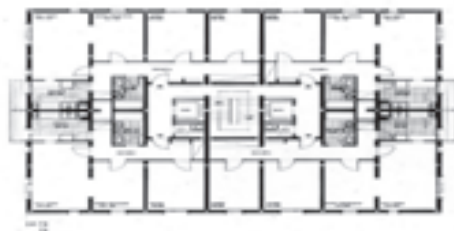


Figure 46 - SAC - Category I1, Tower 1 - Typology T2/T3. Source: Reaes Pinto/ICESA



Figure 47 - SAC - Category I2c, Tower 2 - Typology T2/T3. Source: Reaes Pinto/ICESA

Assembly of the Buildings and details



Figure 48 - SAC - Assembly of the Tower 2. Source: Reaes Pinto/ICESA



Figure 49 - SAC - Assembly of the heavy panels on site. Source: Reaes Pinto/ICESA 1968



Figure 50 - Network of electric tubes in the reinforced concrete belts, in the panels connections area (previous to the concreting). Source: Reaes Pinto/ICESA 1968



Figure 51 - SAC - Assembly of panels on site. Source: Reaes Pinto/ICESA 1966



Figure 52 - SAC - Assembly of panels on site. Source: Reaes Pinto/ICESA 1966



Figure 53 - SAC - View of the first completed buildings. Source: Reaes Pinto/ICESA 1967



Figure 54 - SAC category 2, details of the building. Source: Reaes Pinto/ICESA 1968



Figure 55 - General entrance view / SAC. Source: Reaes Pinto/ICESA 1967

Quinta do Morgado / Encarnação (QM) - (Figures 56 - 61)

This housing unit refers to a public tender for Conception/Construction promoted by Municipality of Lisbon and it is located in Lisbon, in Bairro da Encarnação. This urban area occupies about 20 hectares and has been developed in a quiet flat area not far from Lisbon airport. The solution adopted is different from the SAC options. QM design has non-concentrated facilities scattered in different areas, according to users' needs. QM users' have some neighbours' residential areas, with facilities such as swimming pools, tennis courts and gymnasium available. QM consists of 1,660 dwellings with similar buildings as the SAC complex residential area and with the similar typologies.

Category, Typology, Assembly and Details of Buildings



Figure 56 - Quinta do Morgado. Source: Reaes Pinto/ICESA



Figure 57 - Quinta do Morgado - Tower Building. Source: Reaes Pinto/ICESA 1969

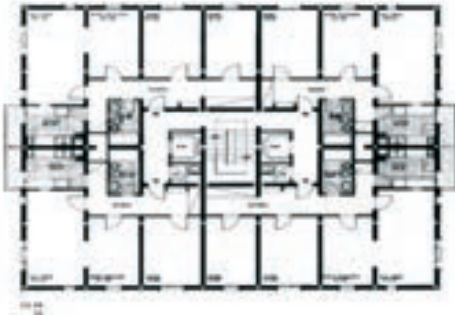


Figure 58 - Quinta do Morgado. Category I1, Tower – Typology. Source: Reaes Pinto/ICESA



Figure 59 - Quinta do Morgado. Horizontal building, Category I2, Tower – Typology. Source: Reaes Pinto/ICESA



Figure 60 - Quinta do Morgado – Tower building. Source: Reaes Pinto/ICESA 2020



Figure 61 - Quinta do Morgado. Horizontal building. Source: Reaes Pinto/ICESA 2020

4. 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 mounting of the moulds (horizontal) out of square, 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 and allows water to seep in, giving the panels an unsatisfactory appearance;
- Microfissures due the 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 the drying of water in the materials which make up the panels to be more difficult. 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 determined tolerance, permitting the entrance of humidity, (Figures 62 – 64).
- 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;

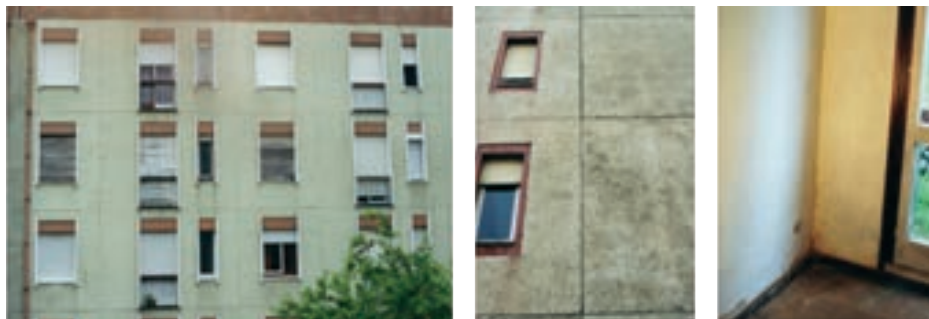


Figure 62 - SAC – Quinta do Morgado. Fissures detected in external surface of the outsider panels.

Source: Reaes Pinto/ICESA 2000

Figure 63 - Quinta do Morgado. Irregular joints width. Incorrect exterior panels assembly or irregularities in the execution of the panels. Source: Reaes Pinto/ICESA 2000

Figure 64 - Quinta do Morgado. Interior humidities coming from exterior panels, caused by the incorrect assembly of the panels or lack of compression in the sellants of the panels joints.. Source:

Reaes Pinto/ICESA 2000

- 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 the 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.

4.1. The Pathologies

The use of new technologies and new materials were 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 has worsened due to improper usage of houses, lack of ventilation and of 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, it is mainly technical aspects of building defects that are considered. 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, demand knowledge of the decay process supported by the building components.

On one hand, the decay process may be started by 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 cause defects. 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).

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 on one hand 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), (figure 65).



Figure 65 - The decay process. Source: CIB 1993

5. Solutions Proposals for Rehabilitation

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 two solution proposals to the problem resolution of the panels' pathologies. The difference between these two solutions is fundamentally the position of the thermal isolation material in relation to the external panels. The characteristics of the thermal isolation material were studied, according to the humidity response, not only to be 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 materials most utilised are mainly expensive moulded polystyrene, with a volume mass apparent of 20 kg/m³, wood mineral boards, with a volume mass apparent of 150 kg/m³, extruded polystyrene, with a volume apparent mass around 20 to 50 kg/m³, and among others, black cork agglomerate, with a volume apparent mass around 90 a 140 kg/m. (LNEC 1995).

The expansive moulded polystyrene was chosen after to study the nature of those materials.

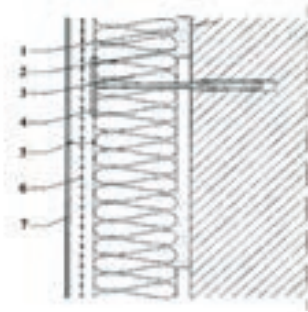
Its characteristics are:

Volume mass apparent.....	20 kg/m ³
Thermal conductivity.....	0.37 W/m oC
Compression resistance.....	> 100 K Pa
Water absorption by capillary.....	reduced
Water vapour permeability.....	0.5 to 4.5 ng/Pa.m.S

Dimensional stability.....< 5 %
 Fire class resistance.....C 1

Source: (LNEC 1995)

Solution 1



Exterior

1. Substract – Brick and concrete Wall
2. Adhesive and base coat. Besides the stick process, the polystyrene should also be fixed by mechanically
3. Thermal insulation – expansive moulded polystyrene in boards, with volume apparent mass around 20 kg/m³ and a thin width 3 cm
4. Mechanical fixing (fastener)
5. Thin external cover – Synthetic framework plaster with flexible fibre polyester. This synthetic plaster is carried out in two applications – The first, will be the base, which applied on the Wall covering. The second, is the finishing cover which is placed in the flexible polyester fibre framework
6. Fibreglass mesh
7. External finishing (final) – Texture paints (waterproof and water vapour permeable)

Figure 66 - Solution 1: The solution developed for the external position of the thermal insulation material on external wall panels. Source: UEAtc 1992.

Solution 1- 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 base on photo reticulated resins (Figure 66). In the last ten years the appearing 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).

The technique presented on Figure 66 was developed in France from 1974 due to the energy savings after the first oil crisis at the end of 1973. It was necessary at that time to isolate buildings with insufficient thermal isolation. This market underwent a significant improvement to 1985, and it has been oriented in 90% to the rehabilitation area. These techniques have been widely adopted by Habitation à Loyer Modéré (HLM), to the rehabilitation of their numerous buildings with insufficient thermal isolation. These companies receive financial aid from the French government. These techniques are carried out with big productivity and low prices (CSTB 1997).

Germany is the European country where this solution was widely adopted, with 35 million of sq. m² by year (against 3 million sq. m² by year in France). This is a result of the application of this solution, not only in the rehabilitation of old but also in new buildings (CSTB 1997).

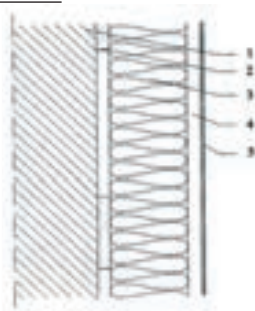
Advantages of Solution 1:

- Hygrothermic bridge makes significant reduction on external walls (in beams and pillars, pavement slab tops, links between internal and external walls). This will increase the effectiveness of the thermal isolation solution;
- Fissuration reduction due by 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 fulfil the structural framework spans;
- Keeping the interior space without reducing its area;
- Trouble reduction on users who continue to live in their homes, due to the structural repairs made on exterior;
- Improvement to the rainwater penetration on external walls resistance.

Disadvantages of Solution 1:

- 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 wall thin increase reclaims an accord with spans and joints between exterior wall panels;
- Spans and joints needs finishing profiles and corner reinforcement;
- Weather (temperature, rainfall, etc), conditions affect the application of this solution.

Solution 2



1. Substract – Brick and concrete wall
2. Adhesive and base coat.
3. Thermal insulation – expansive moulded polystyrene in boards, with volume apparent mass around 20 Kg/m³ and a thin width 3 cm
4. Gypsum cardboard
5. Internal finishing (final)

Interior

Figure 67 - Solution 2: The conception of solution 2 based on the thermal insulation material on external wall panels. Source: Reaes Pinto.

Solution 2 - Industrialised composite panels made by thermal isolation (expanded polystyrene) material pasted to gypsum cardboard in prefabricated panels (Figure 67). Five paste points to the interior covering of the external wall paste these panels. Solutions developed on site by the traditional process are excluded. These solutions on site are more time consuming and dirty.

Advantages of Solution 2

- The heating and cooling of the interior spaces happens more quickly (with less energy losses) in buildings used intermittently;
- Scaffolds are not necessary, except when there are exterior repairs;
- The application of thermal isolation cover, with prefabricated cardboard gypsum by the interior side, is clean and easy to carry out (on the contrary to the covering application on site, separately from the thermal isolations).

Disadvantages of Solution 2

- The solution is not efficient to the hygrothermic bridge correction;
- It implies two front applications, on the outside and inside, when external repairs are required (due to fissuration and deficient sealing on the link joint between two panels);
- Inside space is reduced. The finishing solutions should be compatible with electricity devices, equipment, etc. These adaptations are expensive;
- These interior works affect the user's lifestyle and comfort as they continue to live in their homes.

Solution chosen

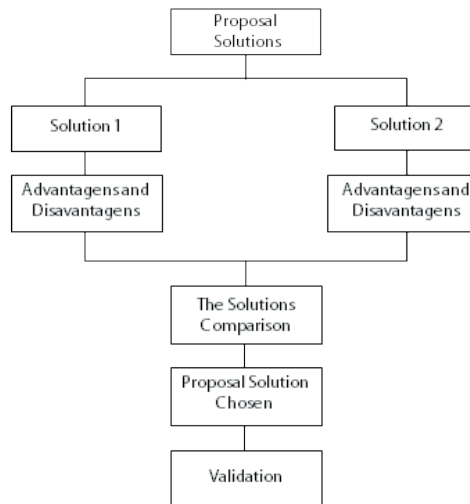


Figure 68 - The solution chosen. Source: Reaes Pinto.

The solution chosen will be found after comparing the advantages and the disadvantages of the two proposed solutions (Solution 1 and Solution 2). This is presented in Figure 68 where the last step will be validation of the solution chosen.

The choice of one of the two solutions studied will depend on the existing anomalies types and location. These anomalies are related to the building external walls from the two case studies and some specific conditioning characteristics which are designed by drivers.

These drivers are mainly:

- The best effectiveness technique in the resolution of these anomalies;
- The driver's environment in terms of their application;
- The development of the works compatible with the user's occupancy in their homes;
- The adaptation and compatibility of the solution to use, its relationship to the building design, economy and durability.

The anomalies detected are located not only on the external side of the panels (micro fissuration and deficient sealing of joints) but also on the inside surface of these panels. These last anomalies are due to the existing hygrothermic bridge and weak thermal resistance on the walls envelope.

The resolution of these structural anomalies will be implemented according to one of these two solutions which have been referred to. Comparing the advantages and disadvantages of the two solutions, in relation to the problems to solve, Solution 1 was chosen.

This solution seems more effective as a result of:

- The hygrothermic bridge and the condensation problems are better solved with the thermal isolation improvement, increasing the thermal resistance of external wall panel;
- The microfissuration appearance due to the difference in thermal amplitude, on the same day or season is reduced. This reduction, in conventional construction, is due to the thermal protection of the resistant structure and the fulfil of structure span, with masonry;
- The repairs are carried out outside and therefore do not affect the users staying in their homes;
- It increases the walls' resistance to the rainwater penetration;
- A significant energy saving is obtained;
- The building aesthetic is improved;
- The interior space area is not reduced.

Final Solution presentation, to resolve External Panels Buildings Pathologies

- Characterization of the final solution, Figures 69 and 70.

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 systems are 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 (on site applied), one of which contains a reinforcement.

The rendering is applied directly to the insulating panels without any air gap or disconnecting layer.

The systems include special fittings (eg. base profiles, corner profiles, etc.) to connect them to adjacent building structures (apertures, corners, parapets, etc.).

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

They should provide a minimal thermal resistance in excess of 1 m². K/W.



Figure 69 - Final solution – Rehabilitation of the external walls of the SAC and QM buildings with an external insulation composite system with rendering. Source: Reaes Pinto.

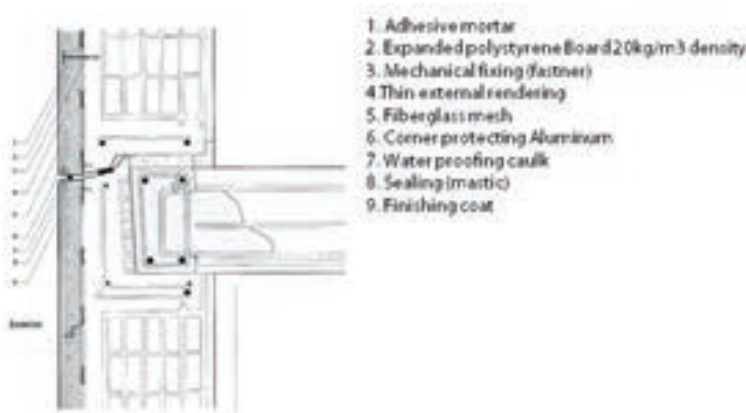


Figure 70 - Final solution – Rehabilitation of the external walls of the SAC and QM buildings with an external insulation composite system with rendering. Source: Reaes Pinto.

The final solution is constituted by - (Figures 71 - 74):

Insulation product - A prefabricated thermal insulation product, the molded expanded polystyrene, with the following characteristics:

Density	20 kg / m ³
Thermal conductivity.....	0.37 W / m °C
Compression resistance.....	100 K Pa
Water absorption by capillarity.....	reduced
Water vapour permeability....	0,5 to 4,5 ng / Pa. mS
Dimensional stability.....	5%
Fire class resistance.....	C1
Dimensions.....	1,20m x 0,60m x 0,03m



Figura 71 - Building work in progress (Instituto Superior de Ciências Sociais e Políticas - Lisboa)
- The insulation boards adhesive coat applied with points and bands. Source: Reaes Pinto, 2000.

The design of the insulating material should have a fitting profile at each end so as to allow an adequate fitting of the pieces and better continuity.

This insulating material is placed on the existing walls after they have been cleaned of any dust, friable material and vegetable micro-organisms. The cleaning process should be done on dry walls, through general brushing, in the case of cracks.



Figura 72 - Building work in progress (Instituto Superior de Ciências Sociais e Políticas - Lisboa) - The insulation boards should be placed in rows with non-continuous vertical joints.
Source: Reaes Pinto, 2000.

The insulation boards should be placed in rows; the vertical joints of the boards, however, should not be continuous, directly on the rigid support and bonded together with adhesive coat (a product used for bonding the insulation product to the wall substrate) and mechanical fixing devices.

The bonding is done with a mixed link mortar (synthetic mortar and cement) applied either at points, with bands or even in continuous application, when degraded walls have peelings with unlevellings over 5 mm (VIERO 2000).



Figura 73 - Building work in progress (Instituto Superior de Ciências Sociais e Políticas – Lisboa)
Special fitting profiles to allow an adequate fitting of the pieces and the better continuity. Source: Reaes Pinto, 2000.

Mechanical fixing is done through special plastic or metal elements, and their number and dimension depend on the state of the wall and the thickness of the insulating panels. The ETA Guideline on ETICS (External Thermal Insulation Composite Systems) (EU 1999) determines the distance between these devices with regard to the periphery of the insulation panels (When the anchors are not place at the panel joints).

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



Figure 74 - Building work in progress (Instituto Superior de Ciências Sociais e Políticas – Lisboa)
The rendering system is constituted by two layers reinforced with fibreglass mesh. Source: Reaes Pinto, 2000.

The rendering system is constituted by one or more layers reinforced with fiberglass mesh applied onto the thermal insulation panels. All the coats are applied on the outer face of the insulation product together with the reinforcement, (ETA Guideline on ETICS) (EU 1999). This rendering is constituted by a first layer - base coat - of mixed link, similar to the adhesive coat mortar, applied directly over the insulating product. Over this still fresh covering layer, the base coat, one would directly apply a reinforcement layer (fiberglass mesh), which would provide most of the mechanical properties of the rendering.

The fiberglass mesh terminals should have a 100 mm overlap. The fiberglass mesh should not be interrupted in wall angles, and it should go on for at least 200 mm.

The fiberglass mesh should be 4 mm x 4 mm, with a mass per m² of between 150 g/m² and 200 g /m². The treatment against cement alkali should be done by using an aqueous dispersion of acrylic resin.

The second layer should be applied after the first one has dried out and it should completely cover the fiberglass mesh. The rendering is applied to the insulation product in one or several coats (application of a new coat on top of an existing dry coat) (ETA Guideline on ETICS) (EU 1999).

Where walls are more easily accessible or subject to more severe actions - as happens with ground-floor walls with public access - a second reinforced fiberglass mesh should be added in order to improve the mechanical resistance of the system to shocks (PAIVA 2000).

On top of the last dry coating layer one should apply the key coat, a very thin coat which may be applied to the base coat and is intended to act as a preparation for the application of the finishing coat.

The finishing coat is a topcoat, which contributes to the protection of the system against weathering and can provide a decorative finish. It is applied onto the base coat with or without a key coat. (ETA Guideline on ETICS) (EU 1999).

Light colours should be used in the finishing coat, whenever possible, as a defence against the aggressiveness of the rays of the sun (Henriques 1994).

The system joints which correspond to the existing prefabricated panel joints should be designed in order to have sufficient width, and the sealant must be formed to the correct cross-section.

Figure 75 shows that if sealant is merely squirted into an open joint, it will not adhere properly to the sides of the joint. It is necessary to insert a strip of backing foam, prior to applying the sealant in order to control the depth and shape of the seal (Endean1995).

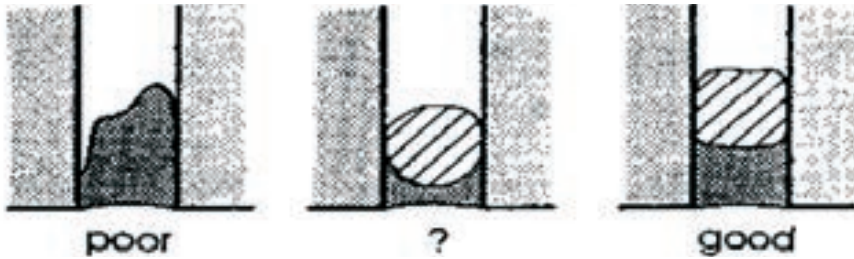


Figure 75 - Panel joints. Source: Endean 1995.

- Backing foam used to control sealant cross-section

This final solution aims at solving the pathologies of the SAC and QM buildings and it will, therefore:

- Allow the global rehabilitation of the panel from the outside, making the most of the means and equipment used;
- Improve the thermal efficacy of external walls, solving the problems of hygrothermic bridges and condensation;
- Make the total thermal capacity of the wall available for the inner thermal inertia of the building;
- Reduce energy consumption;
- Increase the protection against water penetration;
- Reduce fire and toxicity risk;
- Maintain the available inner space, not interfering with situations of inner spans, foot panels, electric equipment, heating devices, etc;
- Preserve the quality of life of the users, not disturbing their activity in the house and improving their comfort.

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 hygrothermal rehabilitation of the external walls of these buildings and their resultant energy rehabilitation but also the improvement of the global quality of the buildings to prolong their lifecycle.

6. Conclusion

The industrialisation of building construction, namely prefabrication, became economically viable in Europe after World War II, due to the severe shortage of new buildings caused by the massive destruction of cities caused by shelling, the high concentration of the population in cities and the increase in the birth rate.

In Portugal, the use of total heavy prefabrication began in the mid-1960s with the aim of contributing to overcome the major structural needs for residential buildings, on the order of 500.000 units per year.

The first experience with this technology was made with the creation of the building construction company ICESA and the implementation of the French total heavy prefabrication process, named FIORIO, with a production of about 10.000 dwellings.

In buildings that are now more than 30 years old, we found anomalies related to design, manufacture, assembly, use and lack of maintenance, a very common situation in Portugal.

In order to identify the type and origin of the anomalies, and to find solutions to rectify them, were conducted interviews with experts and user surveys – 500 for each dwelling unit, SAC and QM, with about 20% answers – regarding the condition of the dwellings.

From the two evaluated solutions for the remediation of this type of anomalies, the first one was chosen, due to its advantages - application of the ETICS system, with the thermal insulation placed on the outside of the external walls of the buildings.

However, in a new eventual rehabilitation of the exterior walls of these buildings we would consider the switch of the expanded polyurethane thermal insulation, a material with a lot of fossil fuel incorporated, for renewable materials such as cork, hemp, rock wool or coconut fibre.

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