PORCELAIN TILE CURTAIN WALLS: A GENERAL REVIEW

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ABSTRACT

The present study emphasizes the advantages of facade cladding in porcelain tile curtain walls compared to traditional adhered claddings, highlighting the system's importance as an alternative, and its potentialities when marketed as a building system. The study also discusses the main parameters to be considered in designing buildings with this technology.

1. INTRODUCTION

Nowadays, facades can be considered the most critical part of building construction in Brazil. When facades are executed in a traditional way, they are open to various technical risks and economic problems. Such problems have often led the facade to become a factor adversely affecting the institutional image of the constructor, which is the primary aspect for his survival in a more and more competitive market.

Maintenance costs have also started to represent very important items in the budgets of national companies. Some building companies in the city of São Paulo are known to have costs exceeding 330.000,00 Euros per year individually, to correct problems of facades clad in traditional ways. The facade also represents, in the sequence of execution of traditional building, the stage of the highest complexity and the major defining agent of the critical state of the services.

For these reasons, the Brazilian constructor, following the example of the constructors of the most developed countries, has looked for alternatives that minimize the risks involved in the production of facades. The market shows itself eager for new technologies that offer comfort, durability and, mainly, the security that the facades built by the traditional methods cannot provide. The major national construction companies look for solutions and they seem to be disposed to pay for alternatives that justify the benefits.

The possibility of separating the cladding and its substrate by introducing a cavity between both layers eliminates one of the main causes of the emergence of pathological problems in facade claddings: the existence of several layers of heterogeneous materials with different thermal characteristics. When they are subject to stresses by intrinsic or extrinsic movements, these layers behave in different ways, causing the emergence of shear and tensile stresses at their interface, which can compromise performance and building durability.

In addition to these advantages, porcelain tile curtain wall technology can present the following features:

- when the cavity is projected as a ventilated cavity, the convective air chains act as thermal insulation between the exterior and the walls of the building, thus eliminating thermal bridges;
- reduction in the consumption of energy for air conditioning in the interior of the building;
- reduction of the thermal expansion effect in the structure of the building;
- potential improvement of condensation problems;
- improvement of the acoustic insulation;
- notable reduction of water infiltration problems;
- ease of maintenance;
- less dependence on qualified workers (industrialized assembly system);
- high potential productivity;
- reduction in the control stages of materials reception and production.

On the other hand, however, some important limitations can be mentioned. They depend on the degree of rationalization incorporated into the system and can make it more or less competitive, both from a technical and economic point of view. To be noted are:

- absence of performance standards and performance requirements adding commercial value to the product;
- need of qualified man power and training;
- dependence on organizational changes in the management and production processes of the enterprise;
- little diversity of complements and accessories adequate for the national construction market;
- requirement of a detailed specific project defining the assembly process;
- high costs when compared to the claddings applied in the traditional way.

2. APPLICATION SITUATIONS

Porcelain tile curtain wall systems can be used as wall cladding or as an integrated system of structuralized vertical wall, applied in combination with glass-reinforced cement board (GRFC), fibrocement boards, and back board panels, among others. Figure 1 illustrates such a description. In this case, the curtain wall is composed of a reticular structure and enclosing tiles, showing flexible modulation, that is, the possibility of adapting itself into pre-existing situations.

The systems generally include a pre-moulded or modular curtain wall, when it is well solved from the point of view of its integration with the other building elements such as windows frames. From that point of view several others advantages arise, as for example:

- productivity improvements during construction;
- possibility of changing of the building construction sequence;
- possibility of changes in the cash flow of the project;
- possibility of purchase of a constructive solution from only one supplier or contractor.

Figure 1: Porcelain tile curtain wall employed as an integrated system with gypsum plasterboards (MÄNTYLÄ, 2002)

It is essential, therefore, that the facade system, as in the case of the porcelain tile curtain wall, be marketed by a supplying company that makes use of an adequate design, planning, execution and management system. It requires that some of the other systems as well as the organization of the construction process be coherent and integrated, unlike what is found when comparing most of the systems currently marketed as *product systems*(*).

It is necessary to sell the applied products with guaranteed performance, that is, as *production systems* (table 1). The requirement of a specific *production system* is based on the impossibility of a single organization holding and efficiently using all the necessary technological knowledge in the production of the various parts of the building.

Component	Ceramic tile
Product system	Board and all necessary complements for the producction
Potential production system	Set of components and project and production methodology
Partial production system	The same + consulting services in: Project, execution (training and assistance), use and maintenance
Constructive system and real production system	Includes: Project, execution, maintenance and responsability

Table 1: Product system and production system of porcelain tile curtain wall.

This position demands an organizational change with the intention of reaching a production process management with high organizational level to enable achieving the sought results. It is a necessary condition for the technical-constructive and economic viability of the concept of the porcelain tile curtain wall system; such a system could be combinable, interchangeable and complementary, and based on modular coordination.

3. CONSIDERATIONS ON THE PROJECT

The design process of the porcelain tile curtain wall can be divided into two distinct phases.

The first one concerns the choice of materials and the study of the feasibility of its use in the building facade. It includes an analysis of the costs of the system in terms of the aesthetic and technical needs and general definitions of technical specifications, detailing and workmanship.

Any production system, however flexible it may be, must be based on pre-established basic parameters. The porcelain tile curtain wall system is not an exception. Although there is always the possibility of adaptations, it should be noted that this usually results in additional costs.

(*)In this paper by *product system* is meant the set of components that complement themselves and supply all the construction needs of one part of the building. It must be emphasized that the guarantee of performance of the applied product is not implicit in this concept, since the responsibilities are diluted between supplier and producer.

Designers must also take into account that the technical solutions need to consider the available equipment, stocking areas and free space for preparation and assembly of the components. Possible interferences with the other contractor works must be considered too. Therefore, porcelain tile curtain wall design must present at least the following features:

a) conditions for the beginning of site work;
b) personal use tools;
c) vertical and horizontal transport equipment;
d) definition of the work platforms;
e) definition of places of storage of devices, components and elements;
f) production team dimensioning;
g) production procedures and techniques;
h) references, dimensions and finishing characteristics of porcelain tile curtain walls;
i) paging of the ceramic tiles in order to prevent cuts and to set architectural parameters;
j) type and dimensioning of the security systems to be used (visible or non-visible);
k) definition of the auxiliary substructure in terms of the type of securing chosen, loads and dimensions of tiles;
l) type and dimensions of the anchors to be used in the substructure securing in the construction wall stage;
m) detail of the linking bridges (anchorage) between the anchors and the auxiliary substructure;
n) surface finishing of the external wall element;
o) detail of the interface of the system with the window frames;
p) detail of the devices placed in the openings of air entrance and air exit;
q) width of the joints between ceramic tiles;
r) type of sealant to be used between the tiles and the supporting auxiliary substructure;
s) distance between the external parameter (back of the tile) and the external wall (size of the cavity);
t) secure techniques for anchorages and rivets;
u) tolerances and ways to control quality.

Design must present in details all the stages of the facade construction including: types of materials, dimensions, finishing, as well as any other information concerning the execution of anchorages and installation.

3.1. SECURING SUPPORTING BASIS

The traditional constructive process used to build high-rise buildings in the city of São Paulo is characterized by the use of reinforced concrete reticulate structure moulded "in situ" and by the use of vertical walls executed as masonry walls made of concrete or ceramic blocks.

The use of walls resistant to flexion compatible with the stresses applied by porcelain tile curtain walls is a significant factor in the cost of the system, since the possibility of anchoring the auxiliary substructure at one or more intermediary points contributes to the decrease of the vertical upright section, causing the reduction of the aluminium mass to be used. Table 2 shows the most common components and the degree of reliability of their use as a base for non-adhered cladding anchorages.

Support Nature	Degree of Reliability
Concrete	Excellent
Massive brick	Very good
Perforated brick	Good
30 mm-wall-concrete blocks	Good
Ceramic brick with small empty cells	Good
Extruded ceramic block	Unacceptable*
Note: In relation to the anchorage dimensioning, besides the material resistance, the situation of joints and the edges of the masonry must also be taken into account. *When used without reinforcements, such as braces, among others.	

Table 2: Degree of reliability of the substrate to be employed as an anchorage base for curtain walls. Adapted from (SORIANO, 1999)

3.2. STRUCTURAL MOVEMENTS

When the external wall cannot be utilized as a support, the anchorages must be fixed directly to the structural elements, such as: beams, pillars and slabs. In this case, it is necessary to assure that the deformation of these elements is compatible with the capacity of the system to absorb deformations, noting that this restriction is imposed on the whole set of elements. The different stresses that act simultaneously in a building must be taken into account. The movements caused by the shortening of the pillars and by the flexion of beams and slabs can subject the claddings to non-foreseen efforts, provoking failures in the wall system or even the collapse of the auxiliary substructure of the cladding.

Among the various stresses the structure is subjected to, the most significant is the movement caused by the creep of concrete, mainly because the slenderness of concrete structures has been increasing in recent years.

According to the American Concrete Institute (ACI), the slow deformation of concrete occurs in the first five years of the building lifetime, and is distributed in the following way over time:

- 50% in the first three months;
- 60% in the first six months;
- 70% in the first twelve months;
- 100% five years after the structure is under normal utilization.

According to ACI, the three main factors directly influencing the ratio of this phenomenon are: concrete curing, time of placing of the in-load structure and type of concrete used. Slow deformation can be represented by the following equation:

$$\varepsilon_{cc} = \varphi . \varepsilon_{el}$$

where:

ε_{cc} = final slow deformation; φ= creep coefficient; ε_{el} = initial elastic deformation.

It can be noted that final creep is directly proportional to the slow deformation (creep) coefficient value, which is situated between 1.8 and 5, that is, $1.8 \leq \varphi = \leq 5$; the value of φ becomes smaller, the:

- longer the time in which the structure remains in humid curing;
- bigger the delay before placing the in-load structure;
- larger the cement content existing in concrete;
- smaller the water-cement factor;
- smaller the concrete porosity;
- larger the deformation module of the aggregates.

The importance of determining and controlling concrete slow deformation (creep) lies in the need to make the structural deformations compatible with the cladding's capacity to absorb these.

3.3. THERMAL INSULATION

Several solutions for thermal insulation have been used in porcelain tile curtain walls. The insulation is normally in the cavity and is fixed against the wall of the building facade. Among the main advantages are the following:

- reduction of thermal bridges;
- increased durability of the wall elements, due to the protection against climatic agents;
- can be applied to buildings without restrictions on its use;
- decreases the possibility of water vapour condensation in the interior of the wall in cold climates;
- is usually cheap.

Some systems use the self-standing fibreglass insulating panel on the external face of the substrate (interior of the cavity), through plastic anchorages. Other authors, as Soriano (1999), recommend the use of polyurethane foam as thermal insulation in ventilated cavity facades.

3.4 THE CAVITY

The cavity can be dimensioned in such a way that the heating caused by sun radiation provides a temporary heat supply to protect the interior environment of the construction in case of a rigorous winter, or it can be projected aiming to remove the excess heat in the summer by the chimney effect. It is, therefore, conceived in accordance with the intentions of the designer. Thus, it can be classified, in terms of the air movement in its interior, as: non-ventilated system (airtight) and ventilated system.

Figure 2: Thermal Insulation (self-standing fibreglass insulating panel) in ventilated facade (MARAZZI, 1997)

3.4.1. Airtight cavity curtain wall

The non-ventilated system is an airtight system, since it does not have openings linking the cavity air with the exterior air. In this case, the exterior cladding also plays the role of air barrier. The airtight cavity is usually between 20 to 50 mm thick and has exterior drainage devices for the water that occasionally passes through the cladding. Figure 3 shows the wall thermal performance provided by the cavity in terms of its thickness.

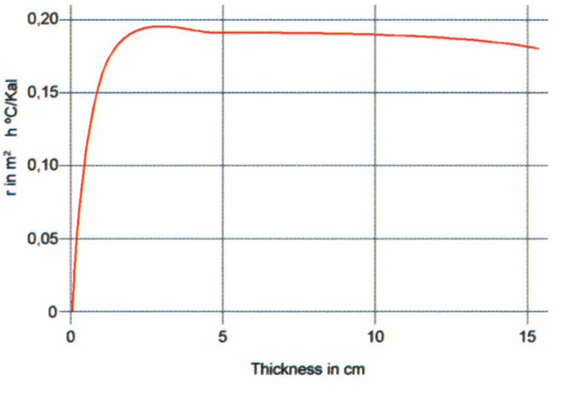

Figure 3: Cavity efficiency in terms of thickness (CROISET, 1970).

3.4.2. Ventilated cavity curtain wall (ventilated facade)

When the cavity is naturally projected as ventilated (not airtight), the heating of the cladding caused by sun radiation provokes a variation of air density in the interior of the cavity, producing an upward movement called "chimney effect", responsible for the elimination, by convection, of warm air, and also contributing to the removal of water vapour (Figure 4). Usually in this type of cladding non-filled joints are used between the components.

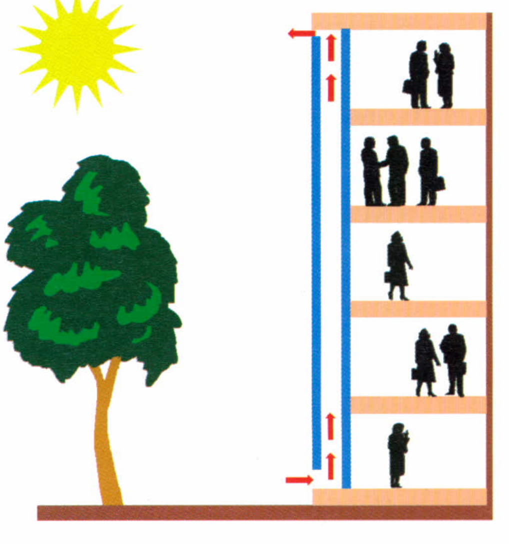

Figure 4: Cavity functioning scheme (CSTB, 2000)

The ventilated system can be characterized as one in which the rain and wind barriers are separated from each other by a ventilated cavity. It normally works by equalizing the interior air pressure with the external pressure, enabling the draining of water that infiltrates the system, and removing humidity through evaporation.

The ventilation performance depends on the maintenance of openings under and at the top of the assembly in such a way that no other building element could interrupt the airflow, causing a localized convective flow.

Authors differ as to the ideal cavity thickness to achieve such an effect. Parício (2000) argues that there is little information on this matter. The author indicates a thickness of 3 cm as lower limit for constructive reasons. As upper limit, this author suggests a thickness of 10 cm, saying that above this, it seems to become useless and counter-productive as well.

The BS 8298 (1994) standard recommends the implementation of horizontal and vertical barriers in the cavity of non-adhered facades, made up of non-combustible materials and resistant to fire for at least 30 minutes. This recommendation aims to provide the compartmenting of certain sections of the facade, making it difficult for fire to propagate between the floors and the horizontal units. In this case, the cavity would be interrupted at each floor, creating several ventilation modules.

3.5. THE CERAMIC COMPONENT

The choice of the components to be used in the execution of a porcelain tile curtain wall must be done based on the aesthetic and technical needs, definition of the general lines and constructive details of the workmanship, and in terms of the composition of direct and indirect costs of the several options, taking into account the cost of inputs, easiness of execution and maintenance.

The factors that directly influence the cost and final performance of non-adhered cladding systems, especially when concerning porcelain tile curtain walls, are several, such as: securing system (visible or hidden, fixed to the building structure or directly to the wall element through anchorages), type of metal used (stainless steel or aluminium), dimension of the elements and quality of the chosen cladding component.

Mäntylä (2001) considers water absorption the most important technical aspect to be considered in ceramic tile facade claddings. This value must be low enough to give the cladding the capacity to be resistant to pollution, erosion and all climatic changes due to temperature.

The flexural resistance of tiles must be high enough to resist the stresses due to the pressure of the wind and accidental shock of bodies, as in the case of the cleaning gondolas. This value is established by the EN 100 standard, around 35 N/mm2. Ceramic tiles of high quality reach values above 50 N/mm^2, therefore it is recommended to use porcelains of the BIa group, GL (ISO 13006)

Though porcelain tiles have excellent mechanical resistance, it is essential to use a safety fibreglass mesh on the back of the tile in order to prevent pieces from falling in case of rupture. This protection can be achieved by using a polyurethane adhesive to glue a fibreglass mesh of 5x5 mm to the back of the tile.

3.6. PAGING AND MODULAR COORDINATION

Paging is an important design part, mainly to avoid cuts of porcelain tiles. It is also important for facade aesthetics. Modular coordination aims to set the positions of the anchors for the attachment of the substructure.

Especially when using visible system, the clips need to be fixed in the base at well defined distances which are set according to the ceramic tile dimensions. In case of using the hidden system each "row" of panels requires the use of two horizontal guides. This explains why large sizes are more economical.

The dimensions of the ceramic tiles generally used as curtain wall claddings have a modular measurement of 300 mm, and their nominal dimensions vary from 300x300 mm to 600x1200 mm. The assembly of most sizes foresees a joint of 8 mm, which remains fixed due to the constructive characteristics.

3.7. VERTICAL AND HORIZONTAL JOINTS

The placing joints are responsible for the capacity to absorb the deformations of structural origin and the expansion and contraction movements of the substrate as well as those intrinsic to the cladding. Moreover, joints are also responsible for cladding watertightness and must allow easy maintenance.

There are two types of joints: open joints (without protection against rain penetration) and closed joints (with rain protection).

3.7.1. Open joints

The joints of porcelain tile curtain walls consist basically of the spaces normally left open, which separate two ceramic tiles, aiming to provide the relief of tensions originating from the intrinsic and external movements characterizing a ventilated cladding.

Considering the behaviour in relation to the actions of climatic agents, the vulnerability of the porcelain tile curtain wall responds to these, precisely by virtue of being left open.

There are five forces that can make water pass through the joints: gravity, droplet, surface tension, capillarity and wind.

Gravity can only make the water enter the cladding, if its edge has an inclined plane enabling it to direct water into the interior of the cavity.

The "droplet" can be understood as being the horizontal component of energy of the rain, which makes the water reach the surface of the cladding at a certain angle, dripping inside the system when the droplets slip over the joint.

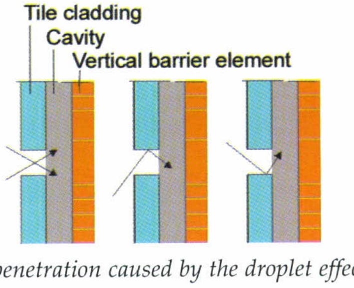

Figure 5: Water penetration caused by the droplet effect (UAF, 2000)

This problem can be solved only by reducing joint width; however, very narrow joints (from 0.01 to 4.5 mm) can create a "bridge" because the surface tension makes the water stick to the surface of the cladding, causing penetration into the interior of the cavity.

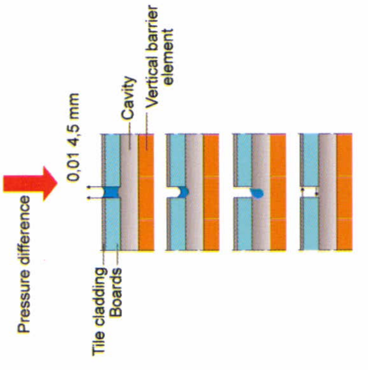

Figure 6: Water infiltration caused by pressure difference due to narrow joints (UAF, 2000)

The ventilation of the cavity contributes to the elimination of the pressure difference between the exterior and the interior of the system, which can occasionally occur due to the effect of wind on the cladding. However, it can be identified as a main factor in the proper functioning of the ventilated facade, for the wall to be airtight, because water can pass through cracks or perforations present on its surface.

The need must also be considered of compartmenting the cavity in very extensive facades, because it is necessary to avoid great variations of pressure in the plane of the wall that could create an intense air movement through the cladding. In case of windy rains, the combination of the width of the joints with the thickness of the component and the direction and speed of the wind can cause water infiltration in the cladding.

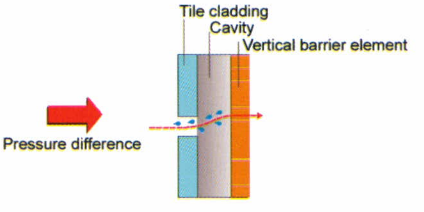

Figure 7: Water infiltration due to leaky cladding and faulty construction (UAF, 2000)

3.7.2. Closed joints

These joints are characterized by the use of an external protection against the action of rain. In this case, it is necessary to complete the cladding with openings and drains to enable equalizing pressures and drain the water that can occasionally enter the system during storms.

Sealants must not be employed, especially silicone, without previously confirming the possible actions of chemical incompatibility with the cladding and the changes of colour due to UV rays. It is important to emphasize that the system does not require any kind of protection of the joints. Any wall protection in meetings with window frames, for example, signifies a badly solved solution of the system (SORIANO, 1999).

It is obvious, however, despite being unusual, that sealed closed joints can be used as a solution in the system, when this is justified.

3.8. DETAILING IN GENERAL PROJECTS OF THE SUPPORTING SUBSTRUCTURE

The typology of the auxiliary substructure is defined in terms of the system used in the ceramic tile envelope, which can be distinguished in two ways: visible coupling system or hidden coupling system.

The detailing of both types of substructures must be done carefully, attempting to avoid the transference of non-foreseen loads in the porcelain tile curtain wall system, avoiding, therefore, the occurrence of pathologies, which, as in any other constructive system, usually originates in the conception stage of the design.

In relation to the tiles, Soriano (1999) says that the safety concerning detachment is related to the section or the contact surface securing/panel. Therefore, punctual inserts are less efficient than anchorage "clips". The author adds that punctual inserts when badly executed, can cause serious damage and even the detachment of the cladding, due to the thinness of the tiles.

3.8.1. Visible fixing system

These systems are characterized by the high productivity at the assembly stage, besides presenting a more versatile, flexible and economic solution, because here the panels need no pre-treatment and are easy to fit, as no horizontal profiles (guides) are used, since the fixing clips are inserted in the vertical uprights.

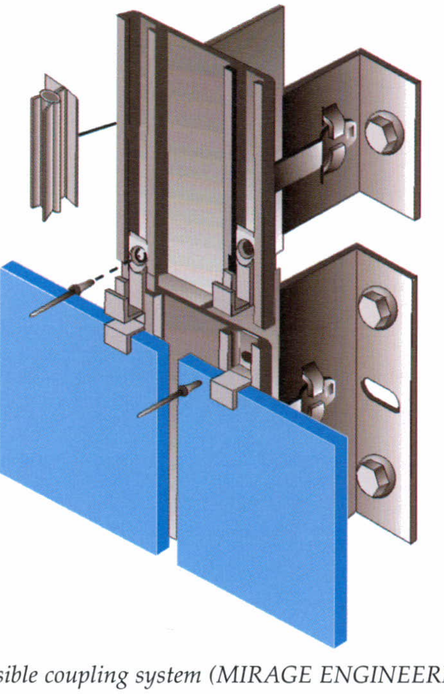

Figure 8: Visible coupling system (MIRAGE ENGINEERING, s.d.)

Here an analogy may be mentioned, for designating these clips, considering the nomenclature used by standard NBR 13707 (1996) and BS 8298 (1994), which classify the devices of the system of stone panelling. These norms classify as retaining, the devices or clips (top) whose function is to prevent the panels from falling, due to perpendicular actions; and as sustaining, the devices (bottom) responsible for holding the weight of the tiles and other vertical actions.

3.8.2. Hidden fixing system

The necessary substructure in this securing method is different from the visible fixing system, as it is composed of anchorage hooks fixed in the back of the ceramic tile and a substructure composed of vertical uprights and horizontal guides. The hooks are fixed by means of 4 (four) screws (threaded in the anchorages inserted in the back of the tile), by means of "self stop" stainless steel nuts. Their function is to allow the coupling between the panel and the substructure.

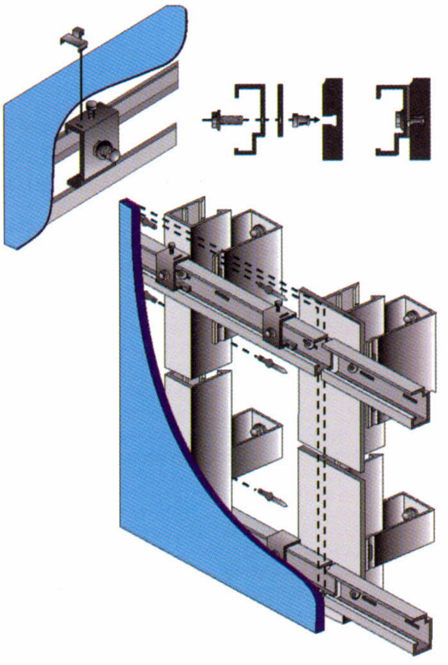

Figure 9: Non-visible securing system (MIRAGE ENGINEERING, s.d.)

4. FINAL CONSIDERATIONS

It can be said that the porcelain tile curtain wall represents an evolution of the production process of building facades, mainly from a constructive point of view due to its high level of industrialization and adequate performance.

One aspect that must be taken into account at the moment of selecting the system is its purchase as a *production system*. with a performance warranty that includes: complete production design compatibility with available workmanship, installation and maintenance as well as durability.

Ceramic tile manufacturing companies must take into account that porcelain tile curtain walls demand a specific technology to fit different market situations and engineering approaches for success. The system's practical implementation must be preceded by a technological development with a view to integrating the system totally with the other constituent elements of the external vertical wall of the building, in order to become a good construction solution for building facades.

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