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Technical and economical viability of facing brick in Portuguese building façades

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Contextualization

The building sector still plays an important role in the Portuguese economy. A continuous search for solutions towards a better performance and economy of the buildings construction will be able to lead to significant improvements in the sector. Considering that masonry represents around 25% of the anomalies of the buildings and represents only 15% of its cost of construction (Lourenço, 2005), masonry must be a subject of special attention in the above-mentioned search. Facing brick (FB) is widely used in many countries, such as the U. S. A. and the European Union's (EU) most developed countries like England, where FB is traditionally used.

This study has the purpose of finding out the reasons why so many countries use FB, and why Portugal does not. FB will be analyzed as an outer panel façade solution, in cavity walls, considering that the material inside fits the functional and regulation demands in Portugal, with special attention to the recent implementation of European normalization. Cladded hollow brick (HB) is the most frequently used masonry solution in the country and will be compared from several points of view with the FB solution. This study will be focused not only on the technical performance, but also on the execution efficiency and the building and maintenance costs.

FB was exclusively used for centuries as a structural masonry solution. It is important to evaluate whether this still is a technique with international implementation and consider the viability of the solution in Portugal. This has become a more viable picture with the creation of the structural eurocodes, which include the structural brick masonry design.

It is important to fit this thousand-year-old material into the technological innovations of construction, analyzing which efforts are being developed at international level to maintain the masonry as a competitive solution, specially FB. An analysis of the market must be done in Portugal so as to conclude which measures should be taken in order to promote a wider application of this solution here.

Historical evolution until the present time

The most ancient bricks, which date back to 10.000 B. C., were discovered near the Dead Sea. Initially they were shapeless and made of mud dried in the sun. Later on bricks experienced several improvements such as the creation of molds and the inclusion of straw in the clay (figure 1). The most important progress was the process of burning the brick that took place about 3000 B. C. Along its evolution brick went through different periods of establishement, undergoing an important impulse after the industrial revolution. Until the appearance of efficient cladding systems brick was used mainly as FB. Many countries kept this trend until the present day. FB was hardly ever used in Portugal, where cladded hollow brick has been increasingly used. The industrial buildings of the first half of the XX century or charismatic buildings like the Bullfighting arena of Campo Pequeno, in Lisbon, are some exceptions. FB has an important role in Europe and in the U. S. A., with several remarkable buildings as the Roskilde cathedral at Zealand Island in Denmark (figure 2). The arrival of FB to Portugal is recent. Meanwhile some notable buildings were built in the last few years. A good example is the Hotel Vila Galé Ópera, finished in 2002.

Fig. 1 – Bricks of mud and straw to drying in the sun (Campbell, 2005).

Fig. 2 – Roskilde cathedral at Zealand Island in Denmark (Campbell, 2005).

Fig. 3 – Hotel Vila Galé Ópera, Portugal.

A worldwide material weakly accepted in Portugal

The main causes leading to the current wide use of FB in several countries of the world are:

- façades with improved aesthetic value;
- high durability;
- low maintenance costs;
- it is a clay brick solution, since it does not produce dangerous waste for the environment (only the burning process);
- allows a great versatility of execution;
- allows structural and non-stuctural walls applications;
- high fire resistance;
- offers good acoustic and thermal performances;
- can be used as an outer panel (non structural) in cavity wall solutions with an inner structural panel.

According to an INE (Instituto Nacional de Estatística) study, the percentage of buildings made of FB in Portugal between the years of 1991 and 2001 as less than 1%. According to APICER (Associação Portuguesa da Indústria Cerâmica), there were only 5 industries producing FB in 2005. Portugal produces four million unities of clay bricks each year, mainly HB. Only 2% of the total production refers to FB. The main reasons for this are:

- FB has not been a tradition building solution in Portugal;
- lack of knowledge concerning specific bricklaying techniques and advantages;
- lack of skilled masons;
- lack of acceptance of new solutions in the construction market;
- lack of regulations regarding the execution of masonry (recently changed with the creation of Eurocode 6);
- absence of masonry design project;
- belief that FB is an expensive masonry solution;
- little importance given to brick application.

Regulation and functional demands

The previous national norms concerning clay brick were from 1964 and 1979 (Portuguese standards NP 80 and NP 834) and were only recently revoked. Norms about masonry execution were completely non-existent. The recent implementation of NP EN 771-1 and Eurocode 6 comes as an update and fills in some gaps, promoting masonry technological convergence in Europe. Table 1 presents the classification of brick unities according to the new legislation, in which FB is a HD (High Density) unit and HB a LD (Low Density) unit. Table 2 summarizes the main demands to fulfill the EC (European Certification).

FB is mainly used in Portugal as an outer panel in cavity walls. When applied this way it has, in many aspects, similar performances to the traditional solutions of HB. A list of building walls functional demands in Portugal is presented below. In each parameter a small comparative analysis is made between the performances of a FB solution versus a HB one:

- structural safety – much better, HB has small compressive strength resistance;
- fire safety – similar, but only if HB is not cladded with inflammable and/or combustible products;
- comfort and health demands – similar, depending on the insulation type; when FB wall cavities and insulation are continuously applied, it becomes a very efficient solution in the elimination of thermal bridges and in the insulation of concrete structural elements; they are both new demands of the Portuguese thermal norm R. C. C. T. E. (Regulamento das Características de Comportamento Térmico dos Edifícios);
- acoustic comfort – better, due to the higher mass per square meter of the outer panel; more studies are needed to allow more conclusive and sustained results; acoustic insulation depends on other factors besides the mass;
- water permeability – slightly worse, only because it requires more care in the execution to guarantee similar performances;
- visual and tactile comfort – slightly better, though it is a subjective parameter; normally FB façades are considered an aesthetic asset it is also a parameter that depends on the quality of execution of each solution;

- durability – much better; FB produces high durability façades with less maintenance concerns; HB needs more frequent maintenance interventions due to its cladding materials;
- economical demands – similar, because it is a parameter that depends on the correct performance of each solution and on the fulfillment of all the stated requirements; objective considerations in this matter will be made further on in the document.

Table 1 – Classification of the brick unities (Dias e Ferreira, 2007).

			Categry I	Category II
Clay brick	**HD**	Net dry density > 1000 kg/m^3	LD or HD unities with compressive strength declared with a probability of fault less or equal to 5 %	LD or HD that does not verify the category I brick demands
	LD	Net dry density ≤ 1000 kg/m^3		

Table 2 – Main demands for clay brick to fulfill the EC (Dias e Ferreira, 2007).

Essential characteristics	Applicability	Observations HD	Observations LD
Dimensions and dimensional tolerances	Brick with predicted use in structural elements applications	Declared values (in mm) and tolerance category (T1, T2, T1, T2)	
Configuration		Declared configuration (presented through drawing or described)	
Compressive strength		Declared value (in N/mm^2) with indication of the direction of the load and of the brick category	
Dimensional stability		Declared value of expansion due to moisture (in N/mm)	
Adherence		Tabled or declared value of the initial shear resistance (in N/mm^2)	
Active soluble salts level		Declared value of active soluble salts level concerning classes S0, S1 and S2	
Fire reaction	Brick with predicted use in elements with fire resistance demands	Fire reaction declared concerning classes A1 to F.	
Water absorption	Bricks with the function of cutting capillarity or in exterior elements of exposed façades	Declared value (in %)	Declared text: “do not leave exposed”
Water steam permeability	Brick with predicted use in outer elements	Declared value (water steam diffusion coefficient)	
Acoustic insulations for direct aerial sound (extreme conditions)	Brick to apply in elements with acoustic requirements	Declared value of net dry density (in kg/m^3) and declared configuration illustrated or described.	
Thermal resistance	Brick to apply in elements with thermal requirements	Declared value of the mechanical resistance (in m^{2}K/W) or equivalent thermal (in W/m.K). The declaration of the evaluation means used is compulsory.	
Frost / defrost durability	-	Declared value demanded by the evaluation method used or declared text: "do not to leave exposed”.	
Dangerous substances	Whenever there is legislation of compulsory fulfillment concerning dangerous substances	The product must be accompanied by documentation that refers the applicable legislation as well as all the information demanded by this legislation, when and where it can be applied and in a appropriate way.	

Manufacturing process and application

There are few differences between the production process of FB and HB. Both include extraction of raw-material, pre-preparation, preparation, extrusion, cutting, drying, burning and packaging. FB requires a more demanding process, especially in extrusion and cutting, because it is very important to remove the air from the clay as much as possible. Cutting must be well done and followed by a process of softening the brick edges. After extrusion several finishing textures can be given to the brick faces, by making them go through specific machines after the extruder. FB is burned at temperatures as high as 1100 ºC. A hydrofugating process is recommended at the end of manufacturing.

FB needs special application care. The most important measures are listed below, concerning an outer panel application on a cavity wall system, with an inner panel made of HB:

- before application: a reference panel should be built allowing to obtain a foresight of the final aspect of the façade and to be a standard of the brickwork expected; the application of the brick must be studied, analyzing the placing of the brick near the corners and openings, the necessary cuts and the thickness of the joint; before starting application, a layer of brick should be placed without mortar to verify the correct application (figure 4);
- bricklaying: bricks should be taken preferably from at least 2 or 3 packs and it is advisable to draw from the packs in vertical lines in order to avoid color differences (figure 5) higher absorption brick should be moistened before mortar application, but never saturating the brick the application always starts from corners or openings, where the brick is previously laid in rows of 6 or 7 (figure 5); this process is successively repeated with special care concerning the horizontality of the upper brick face, the verticality of the wall, the alignment of the joints and brickwork cleaning;
- mortar: it should be a cement and lime mortar, with more consistence and less water than HB mortar; possible compositions of mortar are presented in table 3, suggested by CVG (Cerâmica Vale da Gândara); joints should be finished when the mortar gains some consistency and before drying out; joints can assume several kinds of finishing;
- wall ties and thermal insulation: the outer panel should be anchored to the inner panel; wall ties must have drippings and ca not be tilted in the direction of the

inner panel; projected polyurethane is the recommended thermal insulation; if plate insulation is used, the wall ties should be able to retain the cavity insulation; it is recommended to place five wall ties per square meter and three wall ties per linear meter along openings or movement joints;

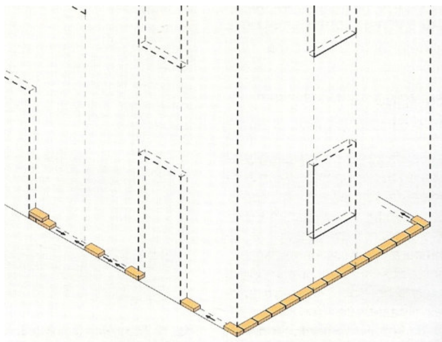

Fig. 4 – Layer of brick placed without mortar to take into account the location of openings (Brambilla, 2001).

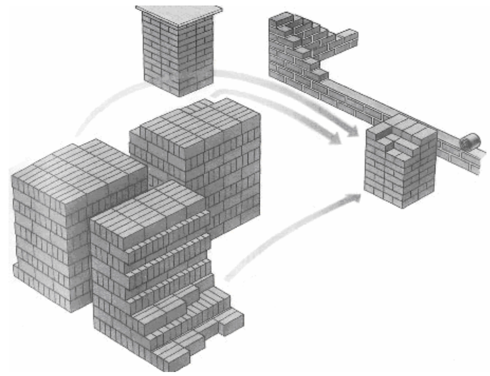

Fig. 5 – Correct way of selecting and applying FB (Powel et al, 2005).

Table 3 – Examples of FB mortar compositions..

Proportions	Cement	Lime	sand	Gravel	Notes
1 : 1/7 : 5	1	1/7	3	2	
1 : 1 : 10	1	1	4 (washed)	6	Cement and lime rustic mortar
1 : 1/4 : 6	1	1/4	4	2	
1 : 1 : 8	1	1	8	-	Cement and lime mortar for solid brick
1 : 1/4 : 5	4	1	14	6	Cement and lime mortar
1 : 1/2 : 8	1	1/2	5	3	Cement and lime mortar
1 : 1/2 : 6	1 (white)	1/2 (hydraulic lime)	6 (fine and white)	-	White mortar

- wall cavity – if plate insulation is used, the inner panel should be finished with hydrofuged mortar; waterproofing membranes should be applied in critical points; the wall cavity must have a waterproofed gutter (figure 6); for water draining and ventilation purposes, the first layer of brick must have open joints, which should never be more than one meter apart;
- movement joints: the vertical ones are more important and should be placed with maximum spacing of 10 to 15 meters; movement joints are nedeed due to tensions

generated by moisture and thermal variations on the FB outer panel; movement joints should be placed in buildings' corners and less commonly in façade openings;

- steel reinforcement: FB walls are more exposed to environmental actions; this generates internal tensions due to size variations that lead to cracking; to avoid it steel reinforcements must be placed in the horizontal brick joints whenever there are concave corners in the façade, for instance due to zones of discontinuity and openings for windows and doors;
- waterproofing: besides the previously mentioned measures for the wall cavity, damp-proof courses (DPC) should be placed; they must not be located less than 150 millimeters from the ground level, at the base of the external walls, to prevent the penetration of rainwater and ground moisture; around the façade openings, for windows and doors, DPC should be applied to prevent moisture from the outer panel reaching the inner panel (figure 7);
- supporting system accessories: there are several stainless steel accessories, such as brick support bases and angles, applied over openings and placed in each storey, respectively; these accessories allow the efforts of the outer panel to be transferred to the building structure helping the anchorage of FB; ventilated façade system can be built with this kind of accessories.

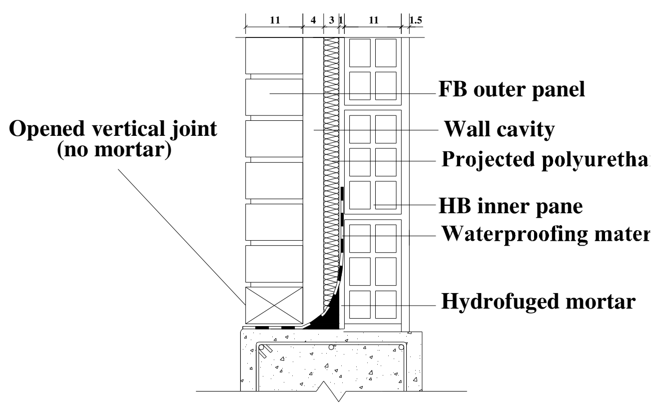

Fig. 6 – FB cavity wall gutter detail (Camarneiro, 2002).

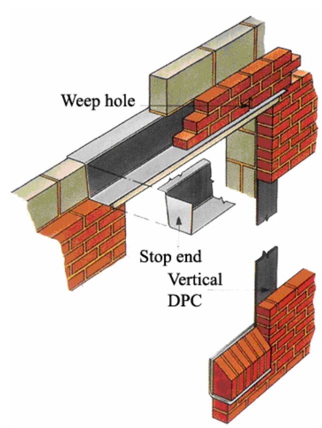

Fig. 7 – Sill waterproofing solutions (Brambilla, 2001).

The execution rate of two cavity wall solutions was analyzed; one with both panels made of HB and the other with the outer panel made of FB. It can be concluded that the two solutions need a similar number of workers to complete a square meter of finished masonry in one hour. The HB solution has a bigger need of painters (48,28%) and masons (3,02%). The FB solution needs more laborers (16,78%).

FB a structural masonry solution

FB was an exclusively structural masonry solution for most of its history. With the creation of the Eurocode 6, this type of application now benefits from European normalization, but its implementation is strongly limited by the demands of Eurocode 8. The viability of the solution in Portugal is still not clear. New constructions in structural masonry are rare in the country. Several Southern Europe countries have similar situations, due to the greater seismic risks. There are exceptions like Italy, which has 30% of the construction made in structural masonry while next-door neighbor Germany has 50% (Lourenço, 2006). England and the U. S. A. also have significant percentages of this solution. FB loses progressively its structural function, due to regulation demands, which lead to the wide use of cavity walls with thermal isolation. Nowadays structural masonry is mainly made of concrete structural blocks in the inner panel, and an outer panel made of non structural FB.

Economical analysis of current solutions and new ones made of FB

The analysis is based on a study made by CVG. The study analyzed the costs of a square meter of completely finished masonry made using three different solutions:

- FB: inner panel in HB and outer leaf made in FB;
- HB: both panels made in HB with plaster and painting in the exterior of the outer panel;
- tile: two panels made with HB covered with ceramic tile (finishing similar to FB walls).

The results are shown on figure 8. It is possible to see that FB is the most economical solution. Nevertheless, more studies should be carried out by reputed entities, to guarantee the validity of the results.

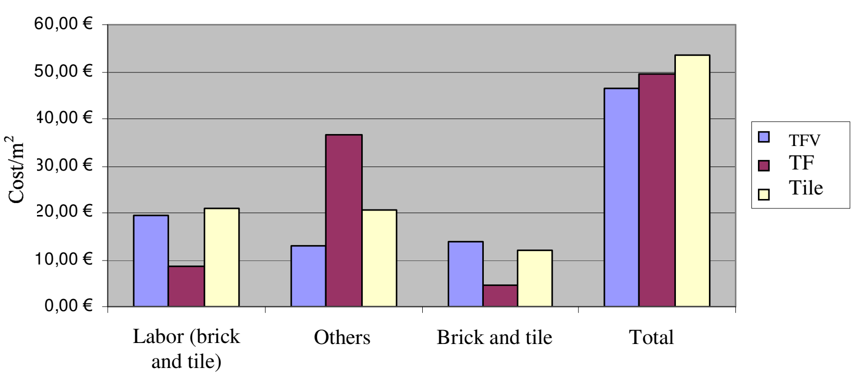

Fig. 8 – Comparative cost analyses of three masonry solutions.

Trends of evolution

The future of FB in Portugal involves the implementation of methodologies of bricklaying similar to the ones already used by other countries of the European Union with more experience in FB application. The creation of masonry design projects and more quality in masonry buildings are some examples of needed improvements in Portugal. A higher receptivity to new construction solutions and a wider uniformity with the European reality are easier goals due to the new norms recently implemented.

There is a world-wide lack of skilled masons for the correct execution of FB masonry. Studies are being developed in subjects like robotics, prefabrication and greater mechanization of masonry application on site. The last two are already applied in some countries in various ways.

Conclusion

FB needs technical conditions to be applied in Portugal. A greater constructive quality demands and masons with specific qualification are needed. The execution efficiency of current HB and FB masonry solution are similar. FB has lower application and maintenance costs and its aesthetic valued in façades is widely appreciated in many countries around Europe. The recent NP EN 771 and Eurocode 6 make the implementation of new masonry construction techniques easier and promote more accuracy in the bricklaying activity. The eurocodes promote a more effective exchange of professionals between different countries as well as the import of new constructive techniques.

FB has little expression in Portugal, therefore there are few comparative studies, concerning this country's reality. Studies regarding technical and economical performance of FB solutions in relation to current HB ones would allow drawing more supported conclusions on the advantages of the usage of FB.

Developing FB application in Portugal would bring greater competitiveness and improvement. This would allow a wider scope of solutions into the national market, which is still very poor when compared to other European countries.

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