PORTUGUESE RECENT DEVELOPMENT OF HIGH THERMAL PERFORMANCE MASONRY SYSTEMS

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ABSTRACT:

The concerns with masonry building envelope performance, particularly thermal efficiency, are causing important masonry solutions changes, mainly in south European countries where traditionally the mild winter climate justified the saving of high thermal masonry wall performance. The new European Directives regulations require different solutions. To answer these new challenges two ways are mainly available, to add higher thickness of thermal insulation in association with current masonry units walls, or to change masonry units, combining improved thermal insulation with enough mechanical resistance. This paper describes the recent development of two new masonry systems, based on light density clay units and lightweight concrete units, intended for construction of large single leaf external walls without thermal insulation materials. A detailed analysis and optimization has been performed by FEM, under thermal and mechanical points of view. Experimental characterization has been carried out to confirm some important characteristics. The concerns with productivity and ergonomic are also considered according their importance to the solution cost.

Keywords*: large blocks systems, thermal performance*

1. INTRODUCTION

Despite the fact that the vertical enclosure of buildings has always been a kind of "face" for these buildings and automatically the subject of particular construction and aesthetic attention, at present there is a growing importance of image and an attempt to exploit the potential of materials and technical solutions, fig. 1.

Figure 1. Counterpoint past/present in construction of buildings

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The walls that make up the envelope of buildings, are one of the features needing improvements, because, despite their economic and functional importance, they are the building elements in which most defects are noticeable. On the other hand the concerns associated with thermal comfort and energy saving are putting pressure on construction in the sense of greater attention towards concerns that in the past were given less consideration. It is in this dichotomy between bolder image requirements on the one hand, and the need to comply with technical requirements, increased performance and acceptable costs on the other, which today presents a challenge as far as façades are concerned.

Traditionally the opaque part of the façades of buildings was usually made of masonry. Now it makes sense to ask whether in future masonry will continue to have such a relevant importance in the construction of buildings, or if, given the technological evolution and development of new materials, it will lose out to other solutions that have better cost effectiveness.

In order for masonry to continue to have a high and distinguishing presence in buildings it would need to evolve, thus ensuring more functions and always at a competitive cost. One of the ways by which the masonry can answer to these new challenges is by using thick single leaf walls with distributed insulation, using lightweight materials as basic raw materials, with good thermal insulation and sufficient mechanical resistance, usually lightweight clay, or concrete [1].

The primary intention of these walls solutions are to achieve, simultaneously, thermal insulation levels without the use of specific thermal insulation materials, adequate mechanical resistance and economic competitiveness. All those purposes must be obtained from the unit cost, but also by productivity gains associated with unit laying. These objectives require the practice of a complex optimization process, integrating various aspects.

2. QUALIFICATION OF THE BUILDING ENCLOSURE

As mentioned, there is a growing emphasis on efficiency in terms of energy, aesthetics and the quality of interior spaces, which lead to higher demands in the building enclosures.

Without minimizing the requirements related to security, stability and durability of the buildings, today it is necessary to take into consideration other concerns to ensure a greater level of well-being for the occupants, in particular in relation to thermal and acoustic comfort requirements. However, this growing importance of well-being, in conjunction with the architectural trends, specifically the widespread increase of the glazed area, has led to an increase in unacceptable energy consumption levels. Thermal comfort requirements demand that the exterior walls contribute towards ensuring comfortable thermal conditions on the inside. To this effect regulations establish maximum permissible values for the overall heat transfer, U value, depending on the location of construction. These values have become increasingly stricter and aim to ensure high levels of thermal insulation, [2].

As far as acoustic comfort is concerned, in general the opaque area of the enclosure guarantees the necessary requirements without implying any major problems. However the increase of glazed panels in the facades, with less acoustic performance, calls into question the compliance with acoustic regulations.

Despite the aforementioned importance of the facades on buildings, they often present performance problems, with frequent malfunctions, due mainly to the following causes:

- insufficient articulation between structure and masonry;
- use of materials of different building systems;
- poorly resolved compatibility problems concerning materials;
- window and door frames with inadequate interface with masonry;
- final quality with excessive reliance on skilled labour.

For the masonry to answer adequately to current needs, there will have to be some improvements and it will be necessary to:

- develop solutions which are better adapted to environmental issues and to the needs of workmanship, by being easier to handle and with less waste;

– increase industrialization by concentrating multiple roles in a single element, generalizing the concept of system with a greater emphasis on pre-fabrication;
– design construction projects more oriented towards execution difficulties, and more concerned with site conditions.

Masonry systems are a set of pieces with different topologies and dimensions, which allow various applications and details to be carried out, seeing the wall as a constructive system for which, in addition to the standard units, individual pieces are also developed to solve all situations.

3. MASONRY PERFORMANCE

3.1. Masonry unit optimization

To ensure that masonry is effectively able to meet all requirements, it is necessary to make changes to the masonry units (blocks or bricks) and their laying process. It is possible to intervene in this optimization process in the following aspects:

– raw material of the units;
– geometry of the units;
– incorporation of other products in these units;
– mortar laying.

Some of these aspects give rise to contradictory effects, for example the high level of heat insulation leads to a generally low level of mechanical resistance. The materials of the "new generation" have a multifunctional nature and can be used in confined or reinforced masonry, or only as simple infill, fulfilling both functions at the same time. Normally these walls are externally covered with render to be painted and generally they demonstrate good performances, including the necessary watertightness. Building with this type of basic component can avoid, particularly in the countries of southern Europe, the use of thermal insulation in the vertical enclosure.

3.2. Thermal optimization

Optimization techniques supported in numerical simulations can be useful in industrial terms, as they enable an in-depth study of the characteristics of the products, avoiding tests of production materials, which are costly in terms of both time and material costs. These simulation techniques can also help to eliminate potential design defects. For the simulation of the behaviour of masonry walls the method of finite elements can be used.

In the particular case of topological optimization of masonry units, the objective is to minimize the overall coefficient of heat transfer of the wall, taking into account the constraints of technological nature associated with the industrial process, walls behaviour and construction [3].

The main factors that influence the thermal performance of units and masonry are the positioning of the holes, the number of rows of voids and their relative position, size, shape and thermal characteristics of the voids, the geometrical characteristics of the mortar joints and the thermal conductivity of the materials, fig. 3.

Since the optimisation problem has an associated discrete domain, a Genetic Algorithm (GA) is adopted to obtain the optimal solution. The GA method is a stochastic search method that borrows the operations and themes from natural evolution. After identifying the design variables and their suitable search domains there exists a multitude of possible solutions that form a solution space. In a GA, a highly effective search of the solution space is performed, allowing a population of strings representing possible solutions to evolve through basic genetic operators. The developed algorithm considers the codification of the data, the definition of the fitness function and a population evolution based on an elitist strategy. The implemented GA [4] is based on four operators, selection, crossover, elimination/substitution and mutation, supported by an elitist strategy that always preserves a core of best individuals of the population.

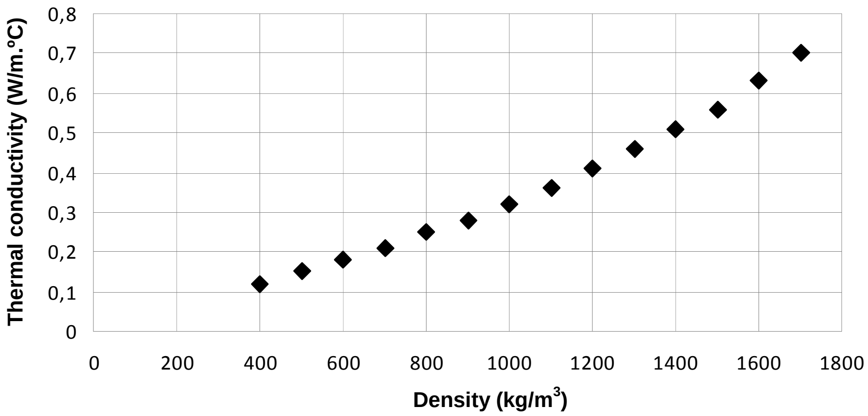
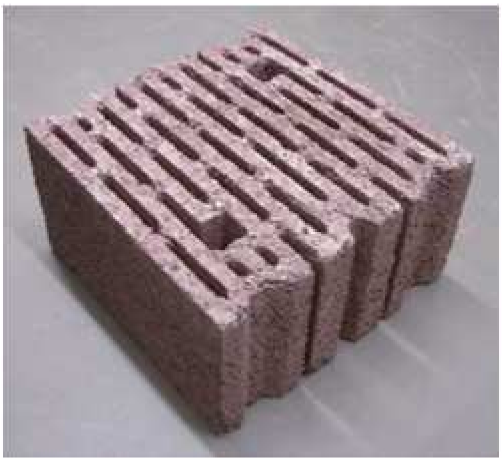


Figure 2. Thermal conductivity versus apparent density of a lightweight concrete with expanded clay aggregates [5]

This numerical evolutionary algorithm iterates over the finite element thermal analysis supported by ABAQUS software. The optimization problem considers an objective function that measures the masonry wall overall coefficient of heat transfer, subjected to the state equations of the thermal problem and to side constraints related with block weight and topology as number of rows of voids, thickness of shells and webs and distribution of voids in each row.

The optimized block of fig.3 has 350 mm in length (including 5 mm vertical mortar joints on each side), 200 mm in height (including 10 mm horizontal mortar joint on the top and on the bottom) and 350 mm in thickness, plus an additional 20 mm mortar at the internal and external render finish surfaces such that the total wall thickness is 390 mm. These values were provided by the manufacturer according to standard building procedures.

The optimal topology obtained for a lightweight concrete masonry unit is presented in fig. 3 and the distribution of temperatures obtained by numerical simulation is in fig. 4.



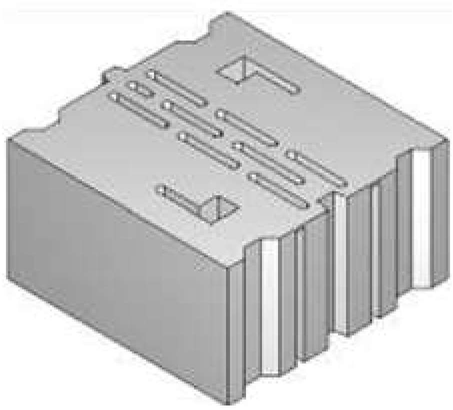


Figure 3. Optimized geometry of the block

The optimal topology of the block corresponds to 16.5 kg in weight and a thermal transmittance of the masonry wall U = 0.48 W/(m^2 K), which is lower than Portuguese standards requests for the more severe climatic zone. This optimal solution exhibits staggered voids and strip bed joints on alternate rows. With this geometry, elongation of the heat flow path through the wall was attained. The open surfaces resulting from strip bed joints need proper technology, already available and used in building industry, in order to avoid mortar filling the air spaces and consequent performance deterioration.

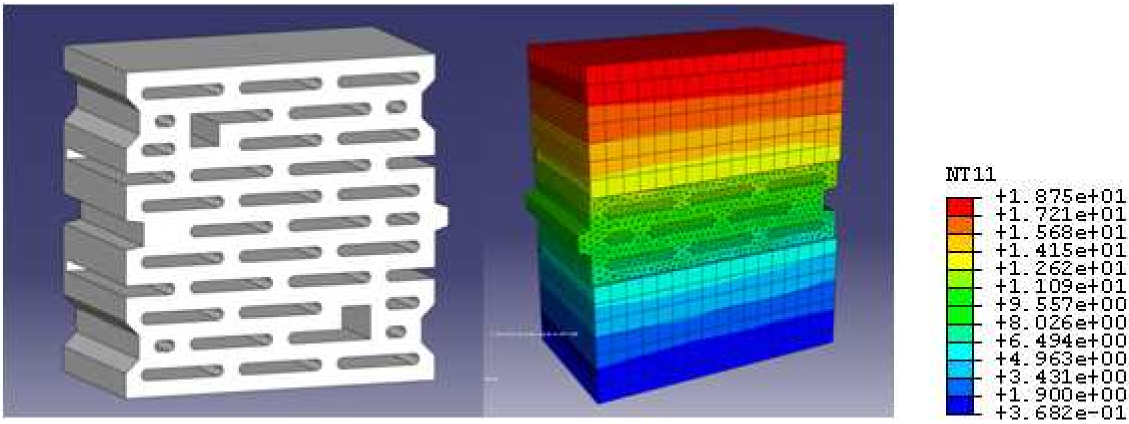


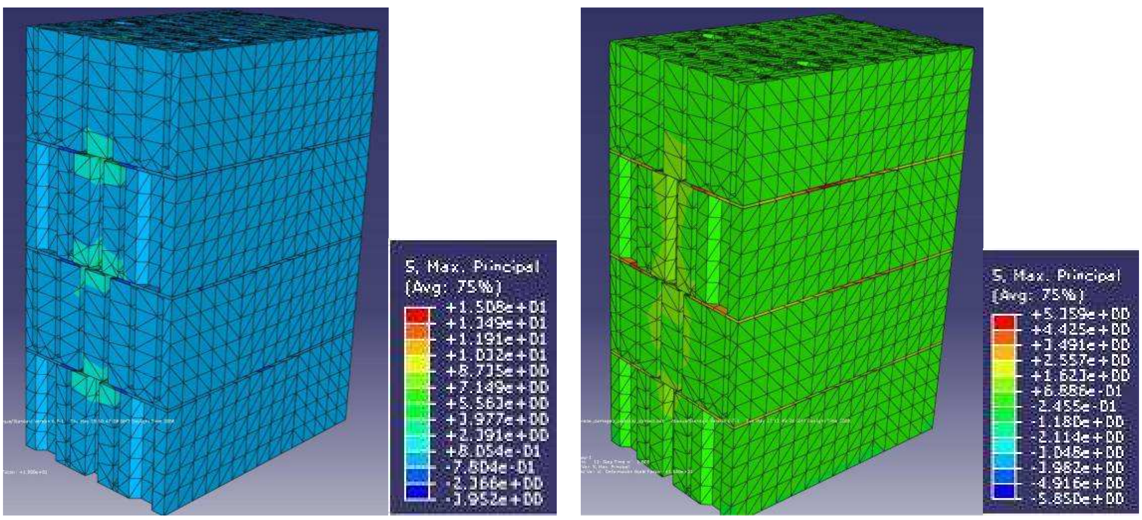
Figure 4. Distribution of temperatures in rendered block for optimal design solution based on external and internal temperatures of 0ºC and 20ºC respectively

3.3. Mechanical improvement

The "new generation" basic materials, in addition to the requirements of thermal comfort, must meet the minimum requirements concerning mechanical resistance and stability. Eurocodes 6 and 8 [6, 7], as well as a vast set of recent standards, point to requirements for these materials as well as for structural masonry, many of them also applicable to infill masonry, taking into account the minimum strength that this kind of wall must demonstrate. These requirements concern the geometrical characteristics (volume of holes, thickness of webs and shells), aspects of masonry and detail practices (interlocking and pockets perpend joints), mechanical characteristics and also the thickness of the joints and shell bedded laying.

For the proper characterization of the elements and walls from a mechanical perspective, behaviour simulations, fig. 5, complemented by experimental tests, fig. 6, can be carried out to determine the influence of various characteristics, for example:

– percentage of voids of the units;
– compressive strength of the units and mortar joints;
– units and joints dimensions.



(a) (b)

Figure 5. Numerical simulation of stresses (MPa) in a wall with four rows of blocks loaded according tests results: (a) elastic analysis; (b) elasto-plastic analysis

For the optimized lightweight concrete block of expanded clay two numerical simulations were performed, considering elastic and elasto-plastic behaviour of the concrete respectively. The corresponding principal stresses are shown in Fig. 5. Non-linear results, as expected, are closer to the experimental results namely the displacements and the failure load.

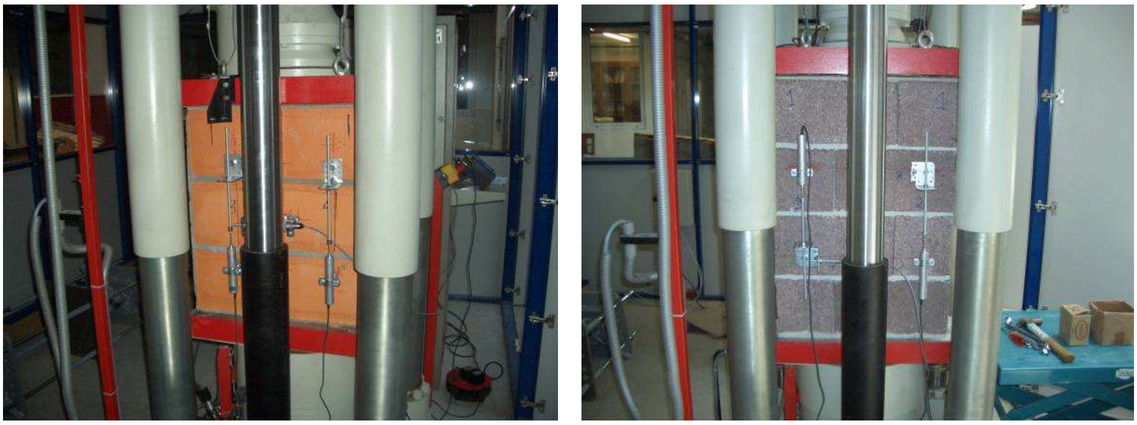


Figure 6. Mechanical characterization tests for masonry

3.4. Productivity/Ergonomics

These "new generation" materials should be developed taking modular coordination into account in order to ensure that these parts can adapt better to the length and height of panels and to the layout of the spans, fig. 7. Additional parts of the constructive system must also respect modular coordination logic, by maintaining the displacement of the vertical joints between layers, and adapting easily to the modulation of finishings or of other building materials.

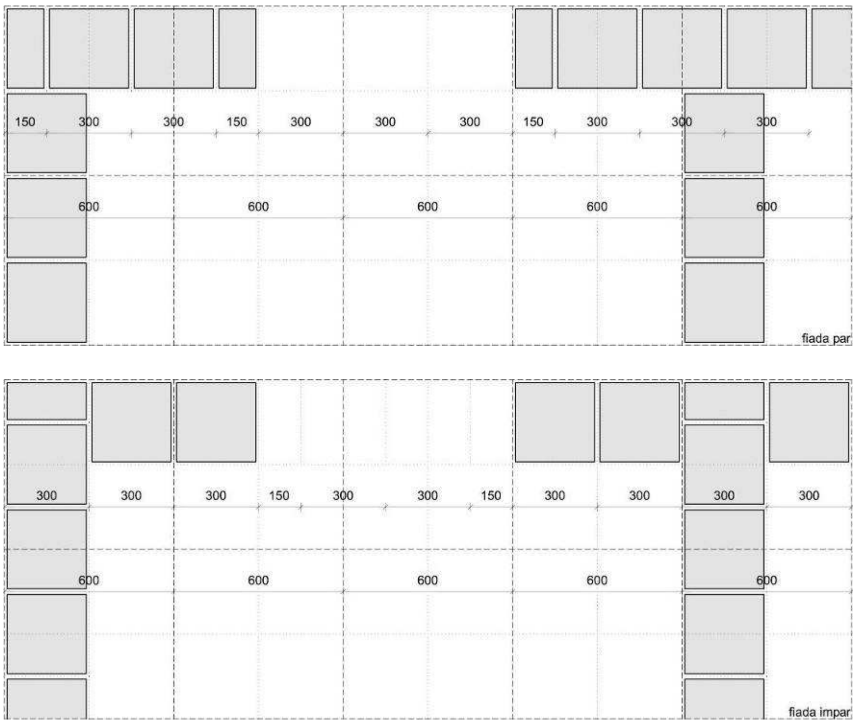


Figure 7. Example of modular system coordination in masonry

The main aspects in the masonry systems improvement regarding economy and productivity factors are:

- increase in facial dimensions, reducing the number of units in the wall;
- an increased thickness can ensure, together with the finishings, the necessary watertightness;
- interlocking joint systems and gripholes facilitate handling on construction sites and increases the speed of laying;
- the use of thin layer mortar joints, in the case of units with a high degree of dimensional accuracy, increases efficiency and the mechanical and thermal performance of the masonry;
- the use of complementary pieces facilitates the resolution of detailing, fig. 8.

The dimensional increase of the units, in addition to the advantages described, highlights one of the main problems of construction using masonry, which is the arduous nature of the workmanship in its laying. This type of task is repetitive and physically exhausting, exposing workers to the risk of serious injury, with grave consequences in terms of productivity.

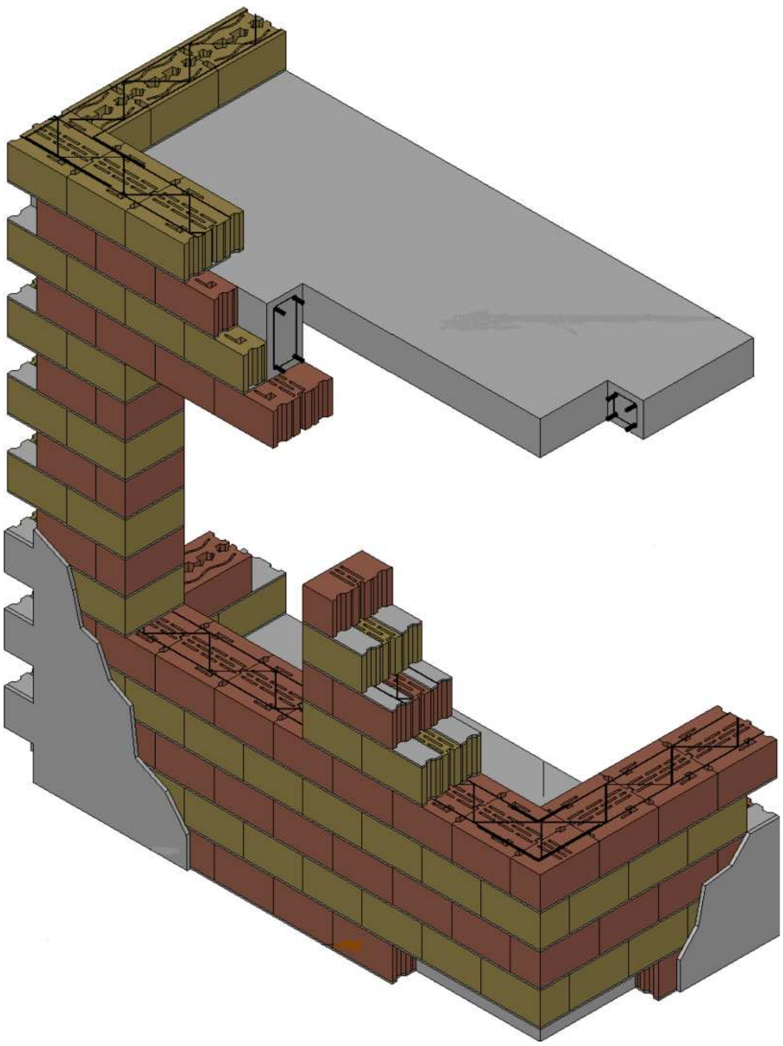


Figure 8. Axonometric projection of a reinforced masonry system

3.5. Current related products

In Portugal, these concerns are starting to be taken into consideration and two different industrial projects, both with the same aim, have been concluded with the participation of Oporto University.

The main objective of these projects was to develop wall solutions that respond adequately to the actual requirements, both with regard to thermal standards, as well as to mechanical behaviour, watertightness and acoustic comfort, and aiming to rely on solutions based on a single leaf wall, reinforced, confined or only simple infill. The use of structural masonry is limited to small buildings.

The scope of OTMAPS project was to develop a block in lightweight concrete of expanded clay aggregates which fulfils the value of $U \leq 0.5$ W/(m^2.C), enough for all Portuguese climate zones [2], fig. 9.

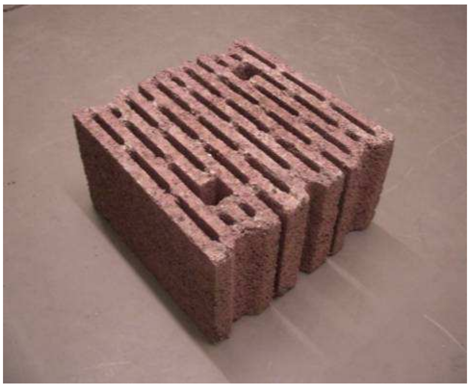


Figure 9. Lightweight concrete block of expanded clay developed in the OTMAPS project

The cBloco project aimed to develop, on behalf of a consortium of Ceramic companies, a ceramic block, whose raw material is a porous ceramic paste, which fulfils the value of $U \leq 0.6$ W/(m^2. C), corresponding to the two climate zones where most construction work takes place, fig. 10.

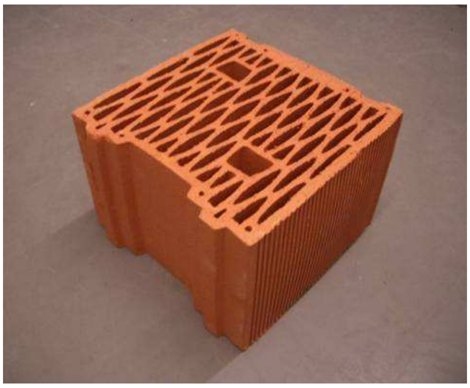


Figure 10. Ceramic block developed in the cBloco project

4. CONCLUSIONS

The construction of buildings is subjected to a set of increasing demands, both at the development stage, but also with respect to the substantial increase of functions and requirements applicable to buildings. This change is particularly challenging with regard to the external enclosure of buildings. The enclosure must ensure, besides the mechanical requirements, most of the requirements of safety, watertightness and comfort, to be able to endure facing all climatic agents, while, at the same time, ensuring an increasingly daring image as demanded by today's architecture.

Taking into account the fact that traditionally the opaque vertical enclosure of buildings is carried out by using masonry, which has in fact evolved relatively little, the need has arisen to re-assess this constructive solution in the light of the above-mentioned developments.

The key aspects of assessing masonry include the upgrading of the component materials with regard to thermal and mechanical perspectives as well as productivity, aiming thus to add various function in the same element. The use of single leaf masonry is justifiable in many situations, using thick, multifunctional elements as a base, integrated into complete construction systems. Ongoing research for the ceramic and lightweight concrete units shows that it is possible to develop at the same time insulating and resistant products, with good laying performance.

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