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Innovative Construction Component

A. Michael[1], M. Eftychi[2] and F. Bougiatioti[3]

[1] Department of Architecture, Faculty of Engineering, University of Cyprus
Kallipoleos St. 75, P.O.Box 20567, 1678 Nicosia, Cyprus
Phone/Fax number: +357 2289 2280, e-mail: aimilios@ucy.ac.cy

[2] Department of Architecture, University of Nicosia,
46 Makedonitissas Ave., P.O. Box 24005, 1700 Nicosia, Cyprus
Phone number: +357 22841500, Fax number: +357 22357481, e-mail: maria.eftychi@gmail.com

[3] Department of Architectural Technology, Faculty of Architecture, National Technical University of Athens,
28 Oktovriou (Patision) 42, 10682 Athens, Greece
Phone number: +30 210 7722017, Fax number: +30 210 7722028, e-mail: fbougiatioti@yahoo.com

Abstract. This paper presents the design process for an innovative modular brick unit, which was based on the principles of bioclimatic and environmentally-friendly architecture.

The design aims at creating an architecturally appealing component, which at the same time can fulfil various bioclimatic functions depending on the prevailing climatic conditions and the building requirements. The presented design proposal was a winning entry at the international architectural competition "Brick-stainable: Rethinking the Brick", organised by Potomac Valley Brick.

Key words

Innovative Construction Component, Energy efficient Component, Multidisciplinary, Sustainability, Integrated design.

1. Introduction

The life cycle of building materials and components includes the phases of extraction, production, construction, use and rejection. Among these, the construction phase is very important, as it can drastically affect the others. (Anink, et al., 1996) The design and construction of buildings – bearing in mind their future disassembly rather than demolition – can influence their ability to be reused or recycled. This mode of construction (Evangelinos, 2004; Berge, 2003) is being referred to with the term ADISA (Assembly for Disassembly), stressing that the principles that should be followed during the construction of a building should aim at the separation of its different layers (site, structure, skin, services, space plan and mobile equipment), the possibility of separation of materials within each layer and the use of standardised components made of one single material (monomaterial components).The afore-mentioned data constitute the starting point of the proposal for an innovative modular brick unit, which is described herein.

2. Design Concept

The proposed brick design is a basic, modular unit characterized by a dynamic design derived from a parametric study. The frame of the particular exploration is more the development of a system rather than a fixed product. Within this process of transformation based on the principles of the developed system, new aspects of the product are realized that enrich the qualities of the specific component. Thus a whole new range of possibilities and variations of the final product is contextualised on a bioclimatic and sustainable basis. The main design concept has been to create a brick, which can accommodate the architectural and morphological views of the architect / engineer, and at the same time provide standardization and climate-responsive design solutions. The main design concept is to create a standardized unit, which can be both architecturally appealing, and promote the bioclimatic function of the building facades to which it is integrated. Consequently, the brick is composed of two distinct elements: the main body and an outer leaf separated by an air gap. The design is based on the standardized production of modular units with different angles and tilts of the outer leaf, which, when combined in a façade element, can produce dynamic shapes and curvilinear surfaces.

Fig. 1. Three-dimensional representation of the design concept.

3. Bioclimatic Function

The principles of bioclimatic and sustainable architecture are integrated with building design through this basic construction unit. The proposed brick facilitates distinct bioclimatic strategies, depending on the requirements of prevailing climatic conditions. Consequently, its dimensions and shape vary according to the performance criteria set in each case. The proposed air gap formed within the façade specifically contributes to improved thermal insulation, based on parametric combinations that produce the desired adaptations demanded by the particular environmental conditions. Depending on the prevailing summer climatic conditions (hot/dry or hot/humid), the design of the brick can be adapted to promote thermal insulation and thermal mass, enhanced ventilation, shading and evaporative cooling.

A. Thermal Insulation Vs Thermal Mass

Thermal insulation is achieved with the filling of the hollow part of the main body with insulation, whereas alternative brick thicknesses provide different thermal mass and time lag values. Furthermore, the air gap created within the façade may be sealed in order to function as an additional thermal barrier.

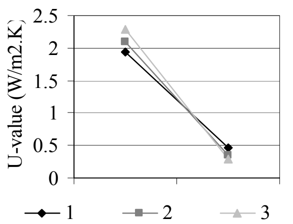

Fig. 2. Graphic representation of the U-value for three brick variations.

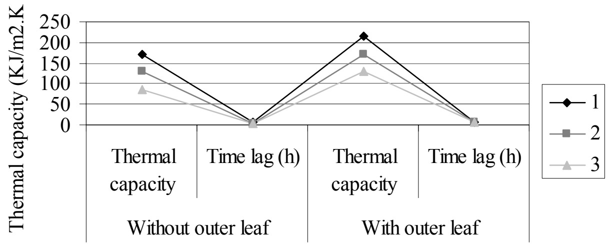

Fig. 3. Graphic representation of thermal capacity and time-lag values for three brick variations.

Table I. U-value and thermal capacity for three brick variations.

no	Dimensions	U-value ($W/m^2.K$) with air gap	U-value ($W/m^2.K$) with insulating material	Without outer leaf		With outer leaf	
				Thermal capacity ($KJ/m^2.K$)	Time lag (h)	Thermal capacity ($KJ/m^2.K$)	Time lag (h)
1.	6 cm brick, 8 cm air gap, 6 cm brick	1.93	0.46	171	4.9	214	7.7
2.	4.5 cm brick, 11 cm air gap, 4.5 cm brick	2.09	0.35	129	4.1	171	6.9
3.	3 cm brick, 14 cm air gap, 3 cm brick	2.28	0.29	86	3.2	129	5.8

Values taken from Ecotect v.5.5
Brick, outer leaf: Density 1700 kg/m^3, Thermal conductivity 0.94 W/m.K
Brick, outer leaf: Density 1700 kg/m^3, Thermal conductivity 0.62 W/m.K
Cork, ground: Density 150 kg/m^3, Thermal conductivity 0.043 W/m.K
Values taken from Transmittancia v.1.0
Brick, outer and inner leaf Density 1700 kg/m^3, Thermal conductivity 0.94 W/m.K, Specific heat 0.84 kJ/Kg.K

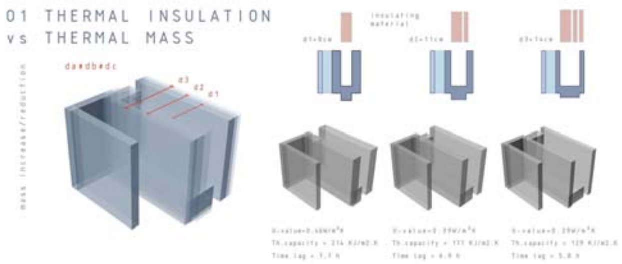

Fig. 4. Design of the three brick variations aiming at promoting thermal insulation and thermal capacity.

B. Cross-Ventilation and Stack-Effect

Cross-ventilation is achieved with specific deployment of the modular units in order to provide a permeable façade, while ventilation as a result of the "stack-effect" is promoted by the air-gap within the building façade. The modular units may be combined in such a way so as to provide a permeable façade with regularly spaced air passages that promote the efficient cross-ventilation of the interior spaces of the building, especially in hot and humid conditions.

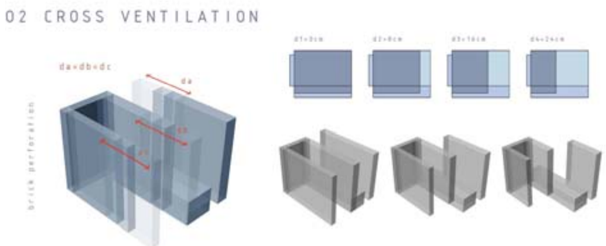

Fig. 5. Design of brick variations based on the air permeability of the facade.

The air gap formed by the modular units may function as a solar chimney drawing heated air from the interior spaces of the building (especially during the summer) or providing fresh preheated air, as in the case of a southern orientated façade with a dark-coloured outer leaf.

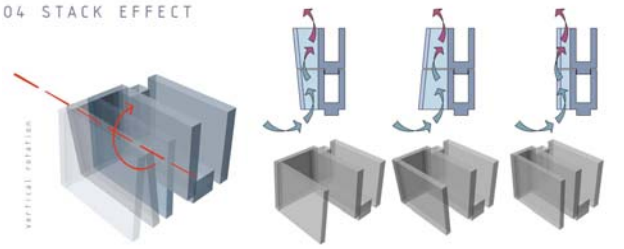

Fig. 6. Design of the brick variations based on its function as a solar chimney.

C. Shading

Shading of the main body of the brick is provided by the outer leaf, with prescribed leaf-angle settings that correspond to different orientations and, consequently, to different sun azimuth and altitude angles during the summer period.

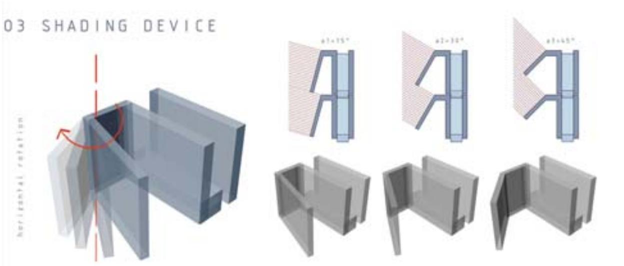

Fig. 7. Design of the brick variations based on different shading possibilities of the façade.

D. Integration of Vegetation

Shading and evaporative cooling (evapotranspiration) can be further promoted through the integration of climbing plants on the permeable “skin” formed by the outer leaf. The design of the air gap and the permeable “skin” formed by the outer leaf can accommodate a “greening” of the façade via the introduction of plants, especially deciduous ones, which, apart from the above-mentioned bioclimatic functions, can further enhance the dynamic character of the structure.

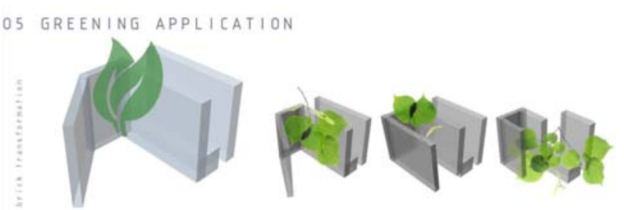

Fig. 8. Design of the brick variations based on the introduction of vegetation to the facade.

E. Integration of Evaporative Cooling Systems

Evaporative cooling can be achieved through the placing of micronisers to the upper part of the façade in order to provide passive down-draught evaporative cooling (PDEC), especially in the case of a hot-dry climate.

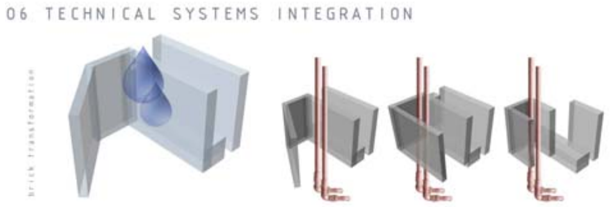

Fig. 9. Design of the brick variations based on the introduction of micronisers to the façade in order to promote evaporative cooling.

4. Construction / Assembly

The modular units interlock one to the other and the proposed construction assembly system is based on a dry-wall construction, without the use of mortar. This aspect of the assembly retains the embodied energy of the manufacturing process, but, most importantly, allows for easy dismantling of the building during the demolition stage and reuse of all its components in new construction. In cases where additional building resilience is required in terms of earthquake loads, there exists the possibility of using vertical steel rods and fasteners to secure the bricks and reinforce the structure.

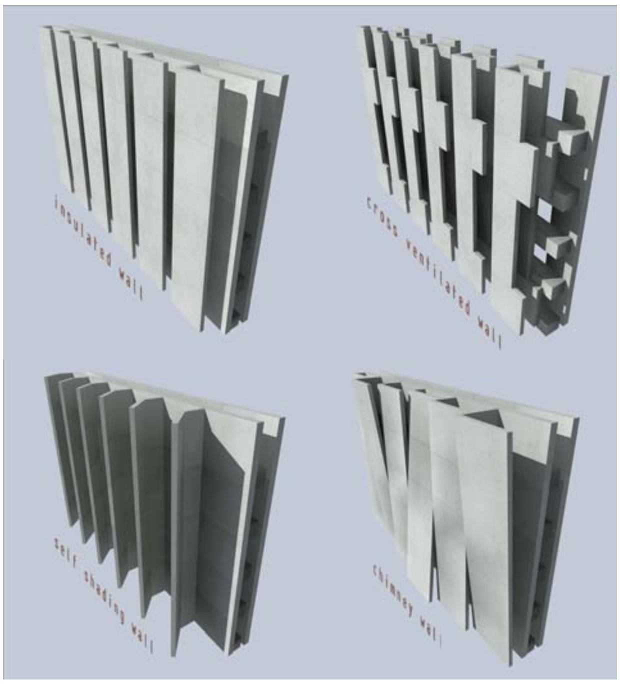

Fig. 10. Different façade assembly based on the brick variations.

5. Conclusions

A. Some Preliminary Findings

The combination of the afore-mentioned strategies allows the application of the proposed brick in different climatic conditions, resulting in the improvement of the thermal behaviour of the outer shell in each case.

Hot / Humid Climate:
Low Thermal Mass + Shading + Cross-Ventilation

Hot / Dry Climate:
Shading + Insulation + Thermal Mass + Evaporative Cooling

Cold Climate:
Thermal Insulation + Thermal Mass + Passive Heating

Fig. 11. combination of the afore-mentioned strategies.

B. Limitations of Implementation

At the present stage, a building façade assembled using the proposed brick can only be developed in a prescribed geometrical configuration. This excludes the creation of concave or convex surfaces and of more complex geometrical forms. Further limitations may arise from the connection of the building façade with the structural frame of the building (posts, beams and slabs).

C. Possible Disadvantages

The large number of brick variations constitutes the most important disadvantage of the proposed design, as it requires a large number of complex moulds that may be hard to accommodate as part of an industrial production line. Alternatively, however, a process of 3D printing / manufacturing may be a possibility, but with the obvious drawback of increased costs. This method is currently used for the production of actual structural elements and, with the optimization of the equipment currently in use, it is expected to present a very competitive solution for proposals similar to the one presented in this paper. Nevertheless, the investigation and development of a dynamic mould that can be used for multiple brick variations could be the answer to this problem, while at the same time it could ensure the customization of the end product given the fact that the parametric mould allows the direct link between the digital design of the modular element and the process of industrial production.

D. Concurrent Advantages & Architectural Parameters of Interest

Apart from the bioclimatic characteristics of the proposed building element, it is important to stress the multiple possibilities for architectural expressionism it presents. The different building variations can be exploited as synthetic elements, which can lead to a variety of architectural design solutions. The combination of different brick variations can create, in terms of the assembled façade design, a sculptural, three-dimensional effect with varying and moving shadows and, in the case of integration with vegetation components, it may provide varying appearances, that give the building an enhanced architectural value.

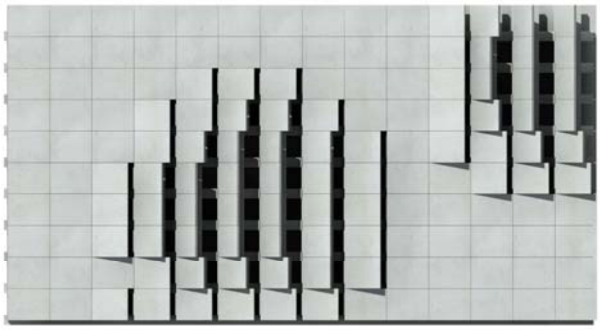

Fig. 12. Different brick combinations leading to different architectural design solutions (façade).

Fig. 13. Different brick combinations leading to different architectural design solutions (perspective).

E. Setting the guidelines for a full-scale study

Further and more detailed research should include a full-scale thermal analysis of different wall configurations in different types of climate in order to quantitatively assess their contribution to the bioclimatic behaviour of the adjacent interior spaces. Further research should also include the chemical composition of the construction material in order for the final product to have enhanced mechanical as well as thermal properties. Finally, the design of the afore-mentioned dynamic mould and its integration to an industrial production line could also constitute areas of further research.

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