

## BR15 - The House of Bauxite

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### Abstract

Under the Removal project a demonstration for the potential of using Bauxite Residue (BR) in building products was conceived in the form of a small informational pavilion. The pavilion is located in the Aspra Spitia settlement, next to MYTILINEOS Alumina and Aluminium plant in Ag.Nikolaos Greece. Using MYTILINEOS BR, BR pavement tiles and BR geopolymerized brick slips were used respectively in the floor and the walls of the pavilion, while vitrified BR was used in used in production of high strength benches and tabletops. The goal of pavilion is to serve as an informational center, showcasing BR reuse technologies and boosting public acceptance for use of BR in commercial applications.

The pavilion is situated at the beach front of the historic modernist settlement by prominent 1960's architect and planner Constantinos A. Doxiadis, himself one of the early figures demonstrating the need and the methods towards a more sustainable turn regarding the science of Ekistics. This presented the project with an important challenge regarding the adaptation of this experimental structure in the overall urban and natural environment of Aspra Spitia. Additionally, the pavilion serves as a continuous testing ground for the functional, aesthetic and technical behaviour of BR materials used, if considering their future commercial development.

**Keywords:** Bauxite Residue, building materials, public acceptance, recycling.

### 1. Introduction

Under the Removal project [1] a demonstration for the potential of using Bauxite Residue (BR) in building products was conceived in the form of a small informational pavilion. The pavilion is located in the Aspra Spitia settlement, next to MYTILINEOS Alumina and Aluminium plant in Ag.Nikolaos Greece. The 'House of Bauxite' was studied and designed by Nikolaos Patsavos and

Alexandros Peteinarelis, architects and researchers affiliated with CRISIS Research Lab of the Department of Architecture at the University of Ioannina and the innovative architectural hub Ctrl\_Space Lab (figure 1). The pavilion is situated at the beach front of the historic modernist settlement by prominent 1960's architect and planner Constantinos A. Doxiadis, himself one of the early figures demonstrating the need and the methods towards a more sustainable turn regarding the science of Ekistics. This presented the project with an important challenge regarding the adaptation of this experimental structure in the overall urban and natural environment of Aspra Spitia.



**Figure 1. Conceptual design and 3D visualization of the pavilion.**

The materials used in the construction of the pavilion were made from bauxite residue. In the past, another bauxite residue brick demonstration house was built in Jamaica, in 1985. In that case bricks were constructed by mixing BR with 6% cement and water and hard pressing the mixture. These 'cement-stabilized red mud bricks' achieved satisfactory compressive strengths but had a high NORM count making them unsuitable for public use [2]. In the Removal project technologies novel technologies were developed to produce safer building materials that comply with all European building and environmental legislation.

The goal for the “House of Bauxite” pavilion is to serve as a continuous testing ground for the functional, aesthetic and technical behaviour of BR materials used, paving the way for their future commercial development. The latter would include a series of concerns, namely: 1. chemical properties and the impact of weathering, especially at a close distance to the sea, 2. production methods of the primary materials and their respective applications, 3. relative composition and implementation specifications and architectural – construction techniques, 4. further architectural applications, 5. optimised correlation between ad hoc, prototyping and industrial methods of production and construction, 6. impact to the public and to the environment.

## **2. BR Materials used**

### **2.1 Geopolymeric Brick Slips**

A new trend in Europe is the application of brick slips to decorate facades of houses. The traditional building block made from fired clay is gradually losing its structural function and slowly merging to a decorative element, whereas the structural function is taken over by prefabricated concrete.

The market for façade materials is increasingly favoring brick slips as an alternative to traditional clay bricks, because they offer a number of advantages over traditional bricks:

- Brick slips save space, making them ideal for renovation projects.
- Brick slips are easy and fast to install, eliminating the need for skilled labor and saving time.
- Once installed, brick slips are indistinguishable from traditional brick walls, proving the same aesthetic while offering the forementioned advantages.

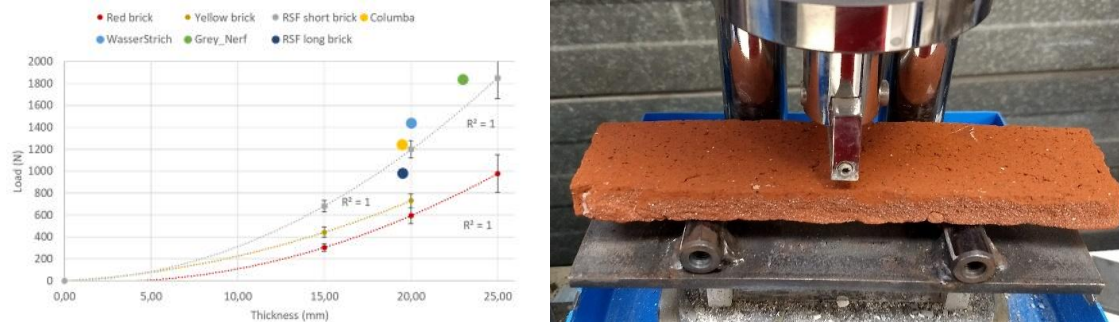
The market size in the European Benelux area for traditional brick production is well exceeding 1610 million bricks per year. The market size for brick slips is a direct competitor to this market, and although it is vastly growing, the total market size is considered to be about 15 – 25% of the total market

The novel developed brick slips are based on waterglass activated slags, i.e. ground granulated blast furnace slag and vitrified bauxite residue [3,4,5] produced under Removal project, for white and black strips respectively. The combination of de-alkalised bauxite residue [6] and ground granulated blast furnace slag results in a red brick slip.

With regards to the energy-intensive process of clay brick making, the presented brick slip provides a sustainable alternative. For the latter, no high temperature step is needed to produce a hardened element that can be applied to the facade. Moreover, currently, brick slips are produced by cutting the sides of a regular clay brick. As a result, 60% of the regular brick is discarded and considered waste.

The brick slips are a non-structural element with rather low liability. The technical requirements are, however, stringent. The limited thickness of the elements, namely, require a high flexural strength to avoid failure of the slips during transport, placement or weathering. Additionally, the slips must be resistant to freeze-thawing phenomenon, since they are exterior elements. And finally, the colour needs to be guaranteed over time. Environmentally, they comply to the Flemish VLAREMA-6 legislation regarding the second life leaching test of building materials.

The dimensions of the brick slips provided for ‘The House of Bauxite’ are 210 x 50 x 15 mm<sup>3</sup> (length x height x thickness). It is, however, also possible to produce longer slips with the developed mix design with a length of 400 mm.

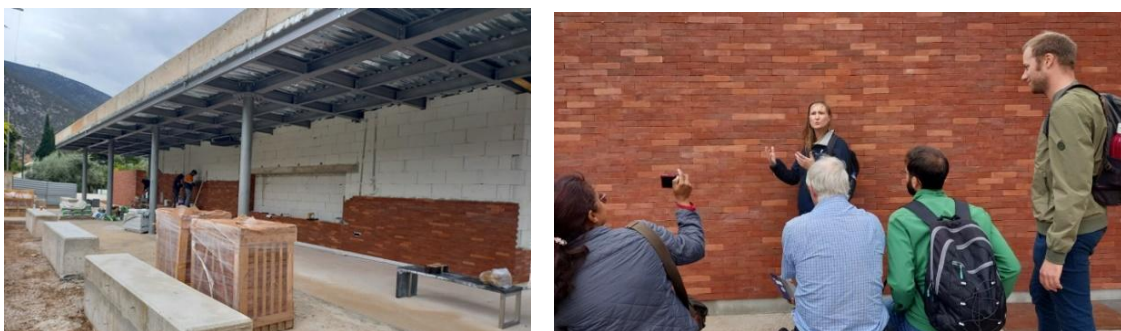


**Figure 2. (L) Flexural strength behaviour of the developed brick slip in comparison to conventional clay brick slips; (R) Brick slip tested in the three-point bending setup.**

The red brick slips are produced by the incorporation of de-alkalized bauxite residue from the Removal project pilot of Aughinish Alumina [7], in a binder consisting out of a secondary raw material from the iron production, namely ground granulated blast furnace slag (GGBFS). The addition of RSF's waterglass activator to the materials results in a hardened brick slip which can be demolded after 16 hours of proper curing.

The flexural strength of the developed brick slips is comparable to conventional clay brick slips (Figure 2 (L-R)) as measured as illustrated in Figure 2 (R). The thickness of the brick slips is determined by the flexural strength performance of the slips. The application of high strength binders allows for a reduced thickness of the slips and thus more slips can be transported at once. The flexural strength of the developed brick slips is higher than 5 MPa after curing. The developed brick slips show very good freeze-thaw resistance, well below 1 kg/m<sup>2</sup>. The resistance to freeze-thaw scaling was measured by means of the CEN TS 12390-9 2016.

Using the de-alkalised bauxite residue produced at the pilot of Aughinish Alumina, red brick slips were developed and 200 m<sup>2</sup> was produced for the demo house at Aspra Spitia. The products were tested on mechanical performance, environmental soundness, resistance to freeze-thaw and colour stability. More than 16.000 brick slips were produced with approximately 600 kg of bauxite residue and shipped to Aspra Spitia. Figure 3 shows pictures of the brick slips installed at 'The Green Red House' and the installation of the strips.



**Figure 1. (L) photo of the application of the BR brick slips in House of Bauxite; (R) photo of final result (from ICSOBA 2022 field visit).**

## 2.2 Concrete Furniture

KU Leuven has developed a mix design using vitrified bauxite for two high-performance mortar mixes, which were used to create large-scale demonstration elements. The mix design for the

elements is detailed in Table 1 and includes a mix without Ordinary Portland Cement (OPC) called Inorganic Polymer and one where part of the binder comprised OPC, which is referred to as blended cement. Both mixes were designed to achieve a compressive strength greater than 100 MPa, with flexural strength provided either through the addition of fibers or steel rebars.

The KU Leuven team designed a sitting bench with dimensions of 0.4 x 0.4 x 1.5 m using an inorganic polymer high-performance mixture. Figure illustrates the bench, which has a thickness of only 40 mm and utilizes solely steel fibers (50 kg/m<sup>3</sup>) as reinforcement. The production of the bench posed challenges due to its thin (40 mm) and long design (1.5 m) and stress built up in the corners of the mold due to shrinkage. The elevated shrinkage of the inorganic polymer mixture resulted in one of the legs breaking during demolding. However, the broken leg was subsequently replaced with a steel frame (Figure 4).

A second bench was cast using a high-performance blended cement mixture, incorporating steel reinforcement in the zone of expected tension instead of steel fibers (Figure 5- L). The casting and demolding process of the bench were successful, with no visible defects observed. Additionally, a table top measuring 1.8 x 1 x 0.025 m was cast with a reinforcement of 50 kg/m<sup>3</sup> of steel fibers (Figure 6 -L). However, this quantity of steel fibers was insufficient to prevent the formation of two cracks. In a subsequent attempt, glass fiber nets with steel rebars were employed as reinforcement, resulting in a tabletop with no visible defects (Figure 6 -M).

**Table 1. Mix design of mortar mixes in kg/m<sup>3</sup> used for the production of demo elements.**

kg/m <sup>3</sup>	Inorganic polymer	Blended cement
Vitrified bauxite residue	539	247
Non-ferrous metallurgy slag	154	-
OPC-CEM I	-	331
Fine silica	-	63
Limestone	77	165
Sand 0/1	417	437
Sand 0/2	885	976
Superplasticizer	-	8
Water	228	192
Sodium silicate	98	-



Figure 4. First Bench. Left: Demoulding, Right: Addition of steel frame to bench for supporting the broken leg.

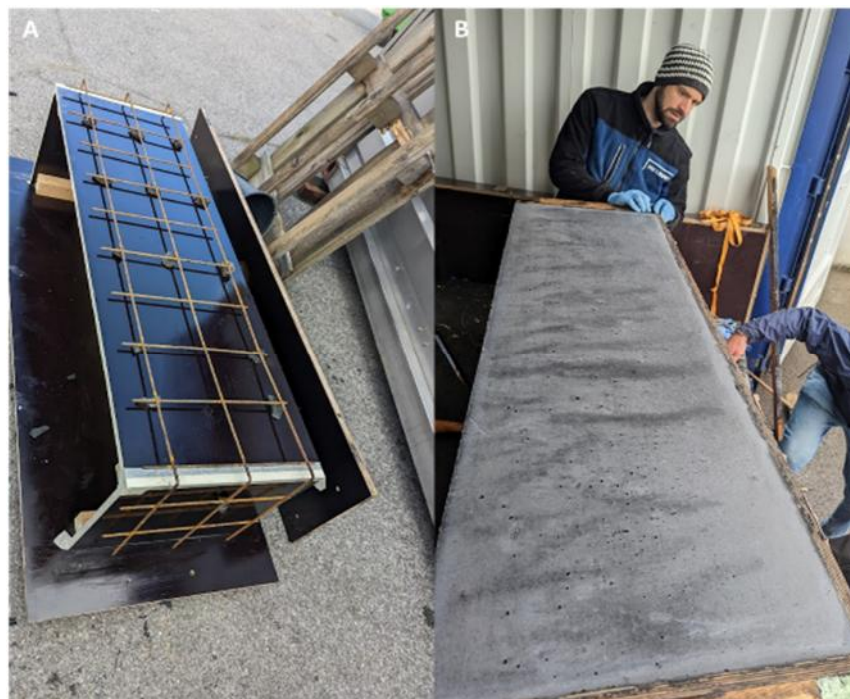


Figure 5. Second Bench. Left: Steel reinforcement in the zone of expected tension, Right: Demoulding.



**Figure 6. Left: Table top using solely steel fibers as reinforcement, Middle and Right: Production and demolding of table top using glass fibers and steel reinforcement.**

### 2.3 Pavement Blocks and Floor Tiles

ENALOS, in collaboration with MYTILINEOS developed pavement blocks and large format floor tiles for the parking area of Aspra Spitia. These materials were developed with the substitution of cement with fresh and untreated bauxite residue reaching a compressive strength after 28 days almost 35 MPa without considering any other additive. Average 20-30% bauxite residue was used to produce each block or tile. After successful completion of the above, 2000 pavement blocks were applied at the parking area of Aspra Spitia. Figure 7 depicts the installation of the pavement blocks at Aspra Spitia.

Moreover, large format tiles with dimensions 1x0.5x0.02cm were also produced with untreated bauxite residue and limestone aggregates (figure 8) and placed in the floor at the demo house. More than 150 tiles were produced in red colour and about 50 with red mud and GGBFS (to get a grey colour according to architect's design). All blocks and tiles produced were tested in accordance to EN 1339:2003 in an external accredited laboratory.



**Figure 7. Pavement blocks developed by ENALOS and MYTILINEOS.**



**Figure 8. Large format tiles developed by ENALOS and MYTILINEOS.**

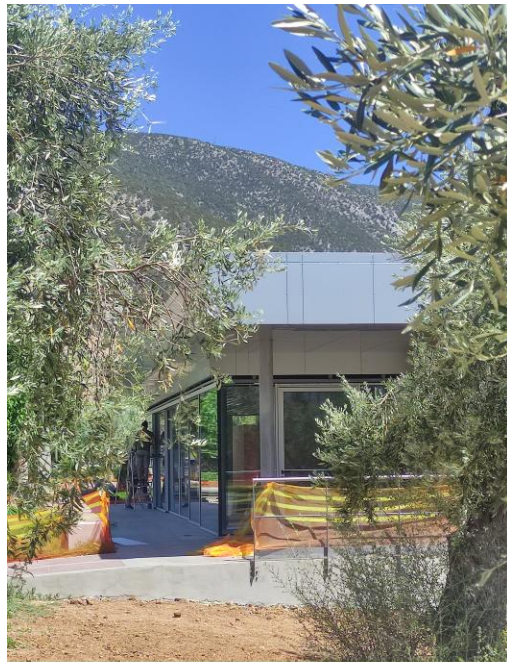
### **3. Architectural Design Concerns, Implementation and Future Use**

In itself, the architectural design process was presented with a series of challenges defining both the architectural characteristics of the pavilion and the methods informing its conceptualization, development and implementation. In short, the most critical issues had as follows: 1. As already mentioned, the new edifice had to be architecturally integrated in the context of Doxiadis's modern heritage settlement, notably one of the most important urban projects of its sort in Greece and Europe in the postwar period. The pavilion follows the scale and spatial differentiation of Doxiadis's buildings (in terms of their relative dimensions and proportions and the fluidity between interior and exterior spaces). Added to that, the new edifice comes as the materialization of an already existing 'desire path' starting from the adjacent public square, defining the main access to it as well as the main exhibition brick wall along it. The pavilion is also connected to the coastal walk and road by means of two new small public places sitting areas, enhancing the attractiveness of this part of the settlement and adding a contemporary landmark and place of activity. 2. Removal materials applied were not standardized industrial ones. Thus, the design evolved a two-way adaptive method feeding the building design model with data steaming out of continuous experiments regarding their physical properties and dimensions, the most appropriate ways to apply them, their relative behavior in the material context of the rest of the standardized building materials prescribed, and their aesthetic optimization (for example the tiles' weathering as observed in other pilot applications in Aspra Spitia). An important decision taken was to invest in the aesthetic correlation between the raw and varied surfacing and coloring of bauxite residue materials and the clarity of the general architectural form and organization. In that sense, what binds the two together is the surrounding nature in a harmonious whole. 3. Following Doxiadis' early synthesis of architecture, planning and ecology, as well as the overall sustainable agenda of RemovAl, the pavilion was designed following international Passive House standards in terms of its energy efficiency. It is also needed to mention that no trees had to be cut in order to erect the new pavilion, and only two olive trees had to be preemptively relocated for their protection, due to their close original distance from the construction site.



**Figure 9: 3D visualisations of the pavilions functional and aesthetic integration to the historic Aspra Spitia modernist industrial settlement by C. A. Doxiadis.**

The construction of the House of Bauxite pavilion was finalized in April 2023. The walls of the pavilion were insulated with the BR brick slips, while the floor of the house and surrounding area with the pavement floor tiles. Two benches and a table produced from KU Leuven with the novel BR hybrid binders were placed within the pavilion. In the photos that follow (figure 9) the final result can be seen. The pavilion will house an exhibition with information and materials on the aluminium value chain and the developed technologies for re-use of the Bauxite residue. In terms of its plan and spatial potential, the pavilion may cater for a series of different open air or closed space events, working together with both its immediate surroundings and the existing garden and square. In time the House of Bauxite will help the local community and all visitors gain trust and acceptance to BR derived building materials.



**Figure 10: Photos from the finalized House of Bauxite in the Aspra Spitia settlement, Greece.**

#### 4. Acknowledgements

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