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THE USE OF RECYCLED CRUSHED CLAY BRICK AGGREGATE FOR THE PURPOSE OF FORMING A PREFABRICATED FAÇADE PANEL

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Abstract. *The contemporary 4R concept of waste management, in accordance with the globally spread trend of sustainability, promotes: reducing the amount of waste at the source, reusing of elements and their parts, recycling in order to produce raw material and recovering of the embodied energy. Discarded bricks from building demolition sites considered in this research could be reused, but also crushed in appropriate facilities and employed as aggregate in various cement composites. This paper investigates the possibility of using such recycled crushed clay brick material as aggregate in a prefabricated composite façade panel with the face of stone, which can be used in a ventilated façade system. It describes the production process of a pilot element, and further suggests the details of the façade cladding technology concerning the proposed element, i.e. its production technology options, as well as transport and installation technologies. The paper further displays various design possibilities of the panel closely related to the production technology options, as well as observed aspects of sustainability and cost effectiveness relevant to the application of the proposed façade panel. The research contributes to the contemporary course of sustainability within the construction industry by proposing an example of forming a new prefabricated building element using recycled building demolition waste material.*

Key words: *recycling, reuse, sustainability, composite façade panel, prefabrication, cladding technology*

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1. INTRODUCTION

Sustainable development is defined as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" [1]. The *4R* approach to waste management highlights as well some of the key principles of sustainable development: *reducing* the amount of waste at the source, *reusing* of elements and their parts, *recycling* in order to produce raw materials and *recovering* the embodied energy. Recycling, addressed in this research, involves melting or crushing of waste materials, extracting component materials in the form of raw materials, which can re-enter the production process. When it is not possible to apply one of the stated actions, only the worst option in terms of environmental protection remains – waste *disposal* at a landfill [2,3].

Application of sustainable design decisions in architecture practice is observed during the entire life cycle of a building: pre-building phase, building phase and post-building phase [4]. Among various methods, sustainable design in architecture is based on the reuse of building elements, use of recycled materials and materials that are recyclable. The benefit of reuse and recycling is the conservation of energy which is embedded in a building element - embodied energy[1], and would otherwise be lost. Reuse and recycling additionally reduce the amount of waste material and demands for the landfill space which is scarce, as well as the extraction of new natural resources and the negative impact of their exploitation [4].

The construction industry is a major consumer of natural resources and also a major producer of building construction and demolition waste [6], where bricks and roof tiles are often found. They could be cleaned and reused, but also recycled in form of crushed aggregate and profitably used for drainage, as a road base, concrete aggregate, etc. Reuse and recycling of brick products should be considered with care, as the consumption of energy during the production of clay products is relatively high. On the other hand, the consumption of energy needed to extract and clean used bricks could amount to only 0.5% of the energy needed for their production. These products could also be milled into pozzolanic powder and used as raw material [7].

Thanks to its wide application and composite nature, concrete is often perceived as suitable for the placement of recycled aggregates, such as recycled bricks, tires, etc. Aggregate constitutes 60-80% of the total volume of concrete, and any reduction in natural aggregate consumption has a favourable effect on the environment [6]. Concrete can be further recycled and used as aggregate within a new cement composite mixture.

Crushed brick aggregate could be used in decorative purposes, for landscaping, in the form of brick fines, chips and nuggets. Constant efforts are being invested in research concerning the possibility of applying recycled waste in mortars and concretes [8, 9, 10], as well as in prefabricated elements as paving blocks [11], solid and hollow masonry blocks [12], etc. The following paper presents a manufacturing process of a pilot element– a composite façade panel with the face of stone, technology of cladding using the proposed panel and some specific aspects concerning its application.

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[1] Embodied energy is the amount of energy consumed during the product life cycle, i.e., it includes the energy necessary for production, transport and disposal of certain products [5].

2. Component Materials

In the section of the designed façade cladding element two distinctive layers can be observed: a supporting base and a decorative face. The base is composed of a lightweight aggregate fibre-reinforced cement composite (mortar) with the thickness of 2.5 cm. The face consists of stone tile mosaic with the thickness of 1.0 cm. The overall thickness of the panel with the area of 60×60 cm is 3.5 cm.

Portland-composite cement based on cement clinker with blended compounds of grinded slag and limestone *PC 20M (S-L) 42.5R (CEM II/A-M (S-L) 42.5R)*, manufacturer Lafarge from Beočin, was used for preparation of the mortar mixture. River sand aggregate (*Moravac*), fraction 0/2 mm, was used as natural aggregate. Recycled crushed clay brick aggregate, fraction 2/4 mm, was used as lightweight aggregate (Fig. 1a). The recycled aggregate participated with 25% in the overall weight of the aggregate added to the mixture (Fig. 1b). Polypropylene monofilament fibres *Sika Fibers*, 6 mm in length, manufacturer Sika, were applied for the purpose of reinforcement. Polymer latex *Sika Latex* and superplasticiser *Sika Viscocrete Techno 20*, manufacturer Sika, were used as additives. Granite *Šutica* from Arandjelovac was used in the form of tiles measuring 10 x 10 x 1 cm to form a decorative mosaic.

a) b)

Fig. 1 Used materials: a) recycled crushed brick aggregate 2/4 mm, b) section of the mortar sample with recycled crushed brick as aggregate

3. Manufacturing of the Pilot Element

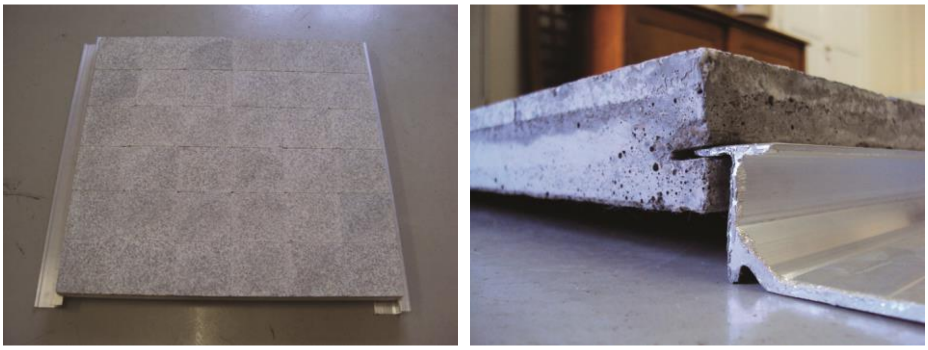
The development of the pilot element was carried out in the Laboratory of Materials, Institute of Materials and Structures, Faculty of Civil Engineering, University of Belgrade. The proposed façade panel is designed as a prefabricated element measuring $60 \times 60 \times 3.5$ cm.

The preparation of the mould with metal strips placed into two of its opposite sides in order to form the grooves involved cleaning, assembling and coating with oil. The manufacturing process started by placing the stone tiles (face down) on the bottom of the mould (Fig. 2a). The tiles were previously immersed in water and placed surface dry, since the loss of water due to capillary absorption of stone might cause a decline of physico-mechanical properties of hardened mortar [13].

A mixer with fixed paddles was used for the preparation of the mortar mixture. The lightweight aggregate was used dry. After homogenization of the mixture containing lightweight aggregate, cement and 2/3 amount of water, the remaining water was added to the mixture. This method is considered as the most favourable, because the lightweight porous aggregate absorbs considerable amounts of water during mixing [14]. Following the manufacturer's recommendations, the fibres, superplasticizer, and polymer latex were added at the end of the mixing process. The total duration of the mixing process was extended to 4 minutes and 30 seconds for the purpose of evenly dispersing the fibres within the cement matrix.

a) b)

Fig. 2 Manufacturing of the pilot element on a vibrating table:
a) mould with placed stone tiles, b) embedding the mortar mixture



a) b)

Fig. 3 The manufactured façade panel: a) the pilot element with placed carrier rails Tabaš, b) a detail

The prepared fresh mortar mixture was poured into the mould, covering the previously placed stone tiles. Compacting was performed mechanically using a vibrating table (Fig. 2b). This kind of a dynamic action achieves very good embedding and compaction, as globules of air get extracted out of the fresh mortar and the mortar fills out every gap in the mould [15]. After preparing, the sample was protected from drying out too quickly, in order to ensure optimal hydration and prevent damage due to rapid shrinkage [14]. Curing procedure of mortars modified with polymers differs to a certain extent from that of conventional mortars, as formation of the polymeric matrix requires dry (air) and cement hydration requires wet regimen of curing (water). For the purpose of achieving optimal properties, the pilot element was subjected to a regimen of 7 days in a humid environment under damp jute cloth (temperature of 20 ± 2 ° C, relative humidity 95%), and 21 days in the air (temperature 20 ± 2 ° C, relative humidity 65%) [16]. The mould was carefully removed 24 h after embedding. Figure 3 shows the panel after 28 days with placed carrier rails.

4. Technology of Cladding Concerning Proposed Façade Panels

The technology of cladding related to the proposed façade panels considers the technologies of production, transport and installation. As it is shown, certain cladding technology procedures typical for stone slabs could be applied in the case of transport and installation of designed composite panels.

4.1. Technology of production

The proposed panel is intended to be a prefabricated element using benefits of industrialization. The direct contact between the stone mosaic and the fresh cement composite mixture is a distinct property of the proposed panel. Façade panels consisting of stone coatings glued to the supporting base, often using epoxy resin, are already widely present in the world market.

The production technology procedures of the proposed façade panels, which are constrained to manufacturing in the horizontal position, follow the making of the individual layers of the system. The manufacturing process of the panels covered with stone mosaic with indistinguishable joints was previously described in the experimental part of the work. The process can be modified according to the technological capabilities of the factory and panel design. Based on examples of various façade cladding elements with the face of stone, the following technological procedures could be considered:

- if the surface of the decorative face is a relief, there is a possibility of placing the tiles face down in a layer of wet sand, or embedding them face up in the already prepared fresh cement mixture [17];
- final finishing of the decorative face after hardening of the mortar base and eliminating the potential deposits of water cement slurry;
- applying a wax coating over the finished face, which is later removed with steam, in order to eliminate the potential deposits of water cement slurry [18];
- incorporating fixings (anchors) during the manufacturing process of the panel (*AirtecStone* [19]);
- mechanical forming of grooves after hardening of the mortar base in order to place the anchors (similar to processing technology of stone slabs);

- modifying or accelerating the curing process of the mortar base (steaming);
- designing a certain mosaic pattern and gluing its face on the paper or its back on a mesh. The paper is subsequently removed, while the mesh remains within the cement composite, etc.

According to the guidelines for prefabricated panels with the face of brick [20], it is possible to consider the technological process of producing a mosaic face with distinguishable joints. There is also a possibility of aligning the tiles in a mould using, for example, special rubber stencils [21]. Processing of joints comes afterwards.

The options of technological production procedures are numerous. Establishing these technological processes, it is possible to suggest different design options apart from the basic design of the panel. Mechanization and automation could be introduced to a greater or lesser extent.

4.2. Technology of transport

After manufacturing the proposed façade panels, it is necessary to provide their transport from the factory to the building site. They can be transported, stored and installed in the same manner as stone slabs. When handling the designed panels, special attention should be paid to the protection of edges which are weakened by the forming of the grooves.

Lifting and manipulating with heavy façade panels – proposed composite panels or stone slabs, are usually accomplished by cranes and accompanying equipment. These façade elements could be picked up by A-frames, as well as by slings (Fig. 4a) or lifter clamps (Fig. 4b), etc.

a) b)

Fig. 4 Lifters: a) spreader bar with slings, b) double scissor clamp [22]

Securing the panels, in the storage and during transport, from damage (scratches) and from falling or overturning (endangering the stability of the vehicle), should be achieved with appropriate frames. Designed panels could be stacked horizontally, placed vertically or leaned on a frame (Fig. 5). Impacts during manipulation should be additionally examined. The panels also need to be protected from moisture and extreme weather conditions.

Fig. 5 A-frame [22]

4.2. Technology of installation

The designed facade panels could be installed using the ventilated façade carrier system Tabaš, which is in practice used for the mounting of stone slabs. This façade system consists of carrier rails which directly support the panels, without additional mediating fixings. It includes primary and secondary L-shaped carriers (Fig. 6). The Tabaš carrier system containing 3 mm thick linear aluminum profiles, which could be applied in the case of proposed panels, is used in practice for supporting the stone slabs with minimum thickness of 2 cm (optimum 3 cm).

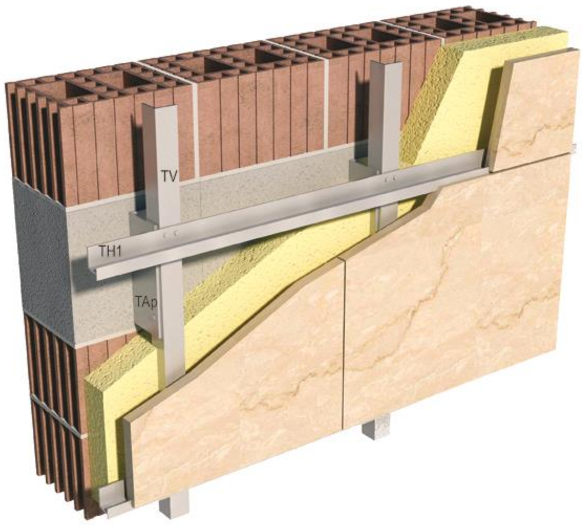


Fig. 6 A ventilated façade carrier system Tabaš [24]

The advantage of a ventilated façade system mostly refers to the elimination of condensation within the façade wall during winter and improved comfort inside the building during summer. The advantage of applying a rail system is reflected in wider application (as primary carriers can be attached only to the supporting structure), reduction of thermal bridges and noise, as well as faster and more precise execution [23].

The direct support by carrier rails which provide continuous support is more favorable in terms of panel durability compared to spot suspension. This type of carrier system additionally enables more precise execution and faster installation. Also, damaged panels are relatively easy to replace.

The proposed carrier system enables the realization of empty (open) joints or filled (closed) joints, usually sealed using permanently elastic materials. Experience in implementing this type of carrier system showed that sealing or downsizing the joints accelerates the circulation of air in the ventilated space, which contributes to the elimination of moisture and condensation within and on the surfaces of a façade wall [24].

5. Aspects of Applying Proposed Façade Panel

The application of the proposed façade panel is further considered from the aspects of design options, sustainability and cost effectiveness.

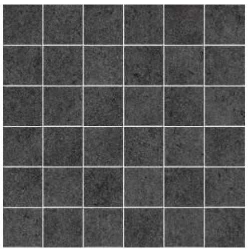
5.1. Design aspect

The design of a façade envelope contributes to its surroundings with an aesthetic appearance and creation of a distinctive ambient. It also represents the period and place where the building was constructed. Bearing in mind the options within production technology of a proposed composite panel with a face of stone, it is possible to introduce the basic classification of such façade cladding elements (Table 1).

In terms of design options, different stone surface finishing could be proposed. The natural appearance of a stone surface can be altered in terms of greater or lesser highlighting of its colour and structure by various processing procedures. Treatment methods could also affect some physical properties of a stone surface. They could improve or worsen properties such as water absorption and resistance to weathering [25]. The applied stone tiles are relatively thin. Impact treatments are not recommended, because they can damage the internal structure of the rock. The tiles may be applied with a natural stone surface which could be smooth or rough. A flat surface can be obtained by cutting in the process of the primary cutting of blocks on boards. Sanded surfaces have a fine rugged appearance. Honed or polished surfaces fully emphasize colour and structure of the stone. Silicate rocks can be thermally treated. Sudden heating of a stone surface causes the formation of fractures and separation of fine parts. The depth of the relief depends on the mineral composition and structure of the rock [25, 26], etc.

Table 1 The basic design classification of the proposed panel

Classification according to the design pattern of the stone face		
Monolithic surface	Geometrical mosaic	Non-geometrical mosaic
		
Classification according to the finishing of the stone surface		
Recommended machine surface finishing	Natural surface finishing	
		
Classification according to the variety of the applied rock		
One rock type applied	Various rock types applied	
		
Classification according to the variety of the applied surface finishing		
One type of surface finishing applied	Various types of surface finishing applied	
		

Classification according to the relief	
Two-dimensional (2D)	Relief (3D)
	
Classification according to the treatment of the joints	
With distinguishable joints	With indistinguishable joints
	

5.2. The aspect of sustainability

The aspect of sustainability of the presented façade cladding proposition is considered from the aspect of sustainable design and materials proposed by Kim and Rigdon [4, 27]. The methods they propose, related to this work are: passive cooling, comfort realization, low embodied energy of used materials, reuse, recycling, using recyclable, durable and non-toxic materials, as well as materials from renewable sources whose extraction doesn't cause permanent environmental damage, reduction of waste during production and reduction of embodied energy by revision of production processes.

The benefit of the proposed ventilated façade system is *passive cooling* provided by air circulation within the continuous air gap in the façade wall (during summer). It contributes to energy rationalization of buildings. The ventilated façade system further contributes to the improvement of thermal, as well as hygienic, health and aesthetic *comfort*, eliminating the occurrence of condensate and mold within or on the surfaces of the façade wall.

It is preferable to use materials with *low embodied energy*. Clay products have relatively high, while recycled raw materials generally have lower values of embodied energy. The extraction and processing of rock material requires relatively low energy consumption, much lower than those needed for the production of cement composites [7]. On the other hand, benefits of cement composites such as mortar which is considered in this research, manufactured according to a designed recipe and under controlled conditions, are constant properties and guaranteed quality. Also, the use of local resources such as local architectural stone and river aggregate used in this research decreases the value of embodied energy of products by reducing the transport route.

Reuse of various building elements, use of *recycled materials* and production of elements which could be *further recycled* supports the concept of preservation of natural materials. The proposed façade panel uses recycled brick aggregate, and it can also be further recycled into the aggregate and used in a new cement composite mixture.

Rock material is considered as *durable material*. Cement composites could also show significant durability by ensuring quality production, carefully selecting component materials and recipes, and providing a design in accordance with the purpose and the environment in which it will be applied. Therefore, the proposed façade panel could be considered as durable, and potentially suitable for a *reuse* within a new building or in reconstruction of existing buildings. Durable materials require less frequent maintenance and replacement, and also provide the preservation of the pleasing appearance of a building.

The use of resources from *renewable sources* is proposed. For example, used rock material - architectural stone and aggregate, are not obtained from renewable sources. The extraction of these raw materials may also lead to *permanent environmental damage*, which could be significantly reduced with contemporary recultivation methods.

The use of *non-toxic (less toxic) materials* and *maintenance using non-toxic agents* is recommended. Natural materials, such as stone, generally have lower toxicity compared to fabricated materials. Dust which occurs as a result of the firing process of clay products could be harmful when inhaled. On the other hand, the finished clay products are chemically inert and do not have harmful effects on the environment.

Reduction of waste during production and *reduction of embodied energy* by revision of production processes are also proposed. Prefabrication of building elements enables the realization of these criteria by creating an optimal design of the production process.

5.3. The aspect of cost effectiveness

The aspect of cost effectiveness of the presented façade proposal can be considered in terms of used materials and the composition of the panel, as well as the proposed industrial production technology and advantages of a ventilated façade system.

In the context of used material, it can be observed that fabricated materials are more expensive compared to natural. In the case of recycled concrete aggregate, it can be noticed that in terms of local conditions (Serbia) natural river aggregate is more affordable compared to recycled. In order to reduce the waste material, it is suggested that these differences are settled by the implementation of certain economic measures [28].

The durability of used materials – cement composites and stone material, would require lower maintenance and replacement costs. It also provides an aesthetic quality - undisturbed appearance, of the whole building façade. From the aspect of aesthetic values, the use of stone as visible covering has an obvious advantage. Durability and aesthetic qualities further contribute to the building market value.

The elements which are obtained by extraction and processing of natural materials, like rock material, are more affordable compared to elements made of composite materials. For example, in the production of conventional concrete the consumed energy amounts 25-70% of the costs [7]. On the other hand, the justification for the use of composites can be found in the designed and controlled quality and preservation of more valuable natural materials.

As a rule, prefabrication is more affordable comparing to construction on site. It focuses on three resources: materials, labor and time. In theory, the reduction of one of these components reduces the overall costs. However, prefabrication does not necessarily imply a reduction of the total budget. Although it can further contribute to save time thanks to the harmonized delivery and the omission of storage space, components manufactured in the factory may initially be more expensive. In numerous examples of contemporary construction, the prefabrication is valued not for lower costs, but for precision in execution and improvement in product quality [29].

Applying a ventilated façade system may increase the overall investment as a result of a thicker layer of thermal insulation (up 10%) due to the cooling of the ventilated space (winter conditions), the carrier system, and the additional finishing of openings where needed. These increased costs are negligible compared to the benefits of a ventilated façade system [30]. They are reflected primarily in the energy rationalization of buildings, interior comfort (temperature, hygiene and health, aesthetics), durability of materials and execution speed. Also, by applying carrier rail system, the replacement of damaged cladding elements is relatively simple. All the aforementioned parameters could be estimated financially.

6. Conclusion

In line with sustainable development in architecture and contemporary trends of waste management, the research is promoting recycling of building waste material. The study presents a possibility of using an environmentally friendly material such as recycled aggregate – in the case of the study crushed clay brick aggregate, to form a new building element – a prefabricated façade panel with the face of stone. The proposed panel can be used within a ventilated façade system.

The production technology options of the proposed panel are numerous, and also the final appearance of the panel which they determine. The proposed transport and installation technologies of the designed panel correspond to those of stone slabs. The research especially highlights the need for the consideration of sustainable aspect of the building elements.

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UPOTREBA RECIKLIRANOG AGREGATA OD DROBLJENE OPEKE U SVRHU FORMIRANJA PREFABRIKOVANOG FASADNOG PANELA

Savremeni 4R koncept upravljanja otpadom, u saglasnosti sa globalno rasprostranjenim trendom održivosti, promoviše: smanjenje otpada na samom izvoru, ponovnu upotrebu elemenata ili njihovih delova, reciklažu otpadnog materijala do sirovine i povratak ugrađene energije. Opeka koja je odbačena nakon rušenja arhitektonskih objekata se može ponovo upotrebiti, ali takođe samleti u odgovarajućim postrojenjima i primeniti u vidu agregata kod različitih cementnih kompozita. Ovaj rad istražuje mogućnost upotrebe takvog recikliranog materijala od drobljene opeke kao agregata kod prefabrikovanog kompozitnog fasadnog panela sa licem od kamena, koji se može primeniti u okviru provetrenog fasadnog sklopa. Rad opisuje proces proizvodnje pilot elementa i dalje iznosi detalje tehnologije oblaganja fasada predloženim elementom, odnosno, opcije tehnologije proizvodnje, kao i tehnologije transporta i montaže. Rad takođe iznosi različite oblikovne mogućnosti panela koje su blisko povezane sa izborom tehnologije proizvodnje, kao i uočene aspekte održivosti i ekonomičnosti u vezi sa primenom predloženog fasadnog panela. Istraživanje doprinosi savremenom pravcu održivosti u okviru građevinske industrije predlažući primer formiranja novog prefabrikovanog građevinskog elementa upotrebom recikliranog otpadnog materijala dobijenog nakon rušenja građevinskog fonda.

Ključne reči: *reciklaža, ponovna upotreba, održivost, kompozitni fasadni panel, prefabrikacija, tehnologija oblaganja fasada*