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CERAMIC FACADE CLADDING AS AN ELEMENT OF SUSTAINABLE DEVELOPMENT

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Gordana Topličić-Ćurčić, Dušan Grdić, Nenad Ristić, Zoran Grdić

University of Niš, The Faculty of Civil Engineering and Architecture, Niš, Serbia

Abstract. *Building in harmony with nature has a small impact on the environment, while meeting the basic needs of the population. Green architecture is a branch of architecture including planning, designing and building of various kinds of buildings, with a low impact on the environment. Construction of the so-called "green structures" is in accord with the concept of sustainability and it attempts to balance environmental, economical and social needs. Environmentally appropriate materials are used in construction of this type of structures, which during their production, application and distribution pollute as little as possible the water, soil and air in the environment. The more sustainable the building materials used for construction are, the more sustainable is the structure and its operation with renewable energy sources. The paper considers ceramic facade elements, i.e. cladding. By using ceramic facade cladding, one achieves a better preception of an urban environment, which enriches our lives for new sensual and visual quality, while observing the green building requirements.*

Key words: *sustainability, green building, materials, ceramic facade*

1. INTRODUCTION

Sustainability and environmental stewardship of building systems is a top priority with the current generation of architects and building engineers. Many manufacturers focus only on product attributes, such as recycled content, often without any consideration of related issues, such as corporate dedication to environmental innovations in product production, or management of life-cycle uses of their product [1,2].

Sustainability is becoming more and more deeply rooted in today's architecture and construction industry and has fortunately - already had an impact on architects of all generations. Designing ecologically sustainable buildings has become a matter of ethics, for human beings are increasingly realising that they need to face up to the consequences of what they do and what they produce, and the effect it has on the land. These opening

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Corresponding author: Gordana Topličić-Ćurčić
Faculty of Civil Engineering and Architecture, University of Niš, 18000 Niš, Aleksandra Medvedeva 14, Serbia
E-mail: gordana.toplicic.curcic@gaf.ni.ac.rs

reflections may seem to be something that ought to be taken for granted, but it is always a good idea to remind ourselves of them, to make sure we not forget the principles governing changes in architecture affecting all architects [3].

But if it is to be entirely effective, sustainable architecture needs to involve all aspects of designing and building, because a couple of trees and a few green touches here or there are not enough, and nor is a focus on a building's surroundings, or an effort to waste less water; we must take all aspects of design and construction into consideration at same time and accept social and ethical responsibility for the places we build in. There are numerous examples all over the world of sustainable architecture built on the basis of ethical principles with respect for the land.

Traditionally, the production of ceramic tiles represented large amounts of energy consumption and significant amounts of inert and toxic waste. Over the last few years, the environmental measures imposed by the governments of the producing countries, and the companies' needs to reduce their costs, improve production efficiency, and increase profits have led to significant alterations in their methods. Between 90 to 95% of the energy consumption of the production process is ascribed to firing. The use of electrical energy and natural gas was the first step, and now researches are being conducted to create a system that utilizes renewable fuels to fire a kiln from start to finish. Other measures have been widely implemented, such as, for instance, the re-use of the heat liberated in firing for supplying energy to drying ovens, and for the production of electric energy; the replacement, whenever possible, of intermittent kilns by continuous kilns, where the temperature levels are more controlled; or the re-introduction of manual tasks instead of machines, which not only reduces energy consumption, but also increases employment, as reported by Russo [4].

At recycling level, the reintegration of both the liberated dust and the conformation waste into the composition of the paste; the transformation of inert waste into dust that may be partially introduced into the composition of the ceramic paste and the re-use/recycling of water in a closed circuit system, have all contributed towards a very significant reduction energy consumption and of the post-production waste. At health impact level, both on workers and users, toxic components are been steadily eliminated, such as, for instance, the use of lead to give gloss and visual depth, replacing them with other non –toxic compounds. With regard to the use of ceramic cladding, several relevant factors can be found in its environmental potential, namely its long life-cycle (which reduces, in the long term, the number of times raw-materials need to be extracted, manufactured, transported, installed, demolished, and debris removed); according to Carter and Norton [5] the fact that it contributes towards temperature regulation, moisture management and high resistance to temperature variation and poor electric and thermal conduction, deriving from the nuclear bonding of electrons; its chemical insensitivity of not absorbing or emitting pollutants because it becomes inert after syntherisation; its easy cleaning and maintenance that does not require chemical treatments; and also because it disintegrates into inert non-allergenic powder. The fact that tiles claddings remain almost unchanged is due, not only to the ceramics' properties, but also to its relation with its support. If the application is in accordance with the standards for each material and the application method is in agreement with the materials' expansion coefficients, and an adequate paste material is used, then the adhesion to the plane will last for a considerable time [6,7].

Researchers have succeeded in producing and testing prototypes of thin-film solar cells (Figure 1) a few microns in thickness that can be deposited on ceramic tile panels using a low-temperature process (plasma-enhanced chemical-vapour deposition).

What makes this innovation for ceramic tile so exciting is that the fabrication of ceramic tile and its application in modular, removable back-ventilated façade systems are perfectly suited to solve the problems with solar cell façade cladding integration that exist with other building materials. Modular construction of back-ventilated tile façade systems may solve problems of inter-connection, as well as access for repair and maintenance of solar cell ceramic panels [1,8].

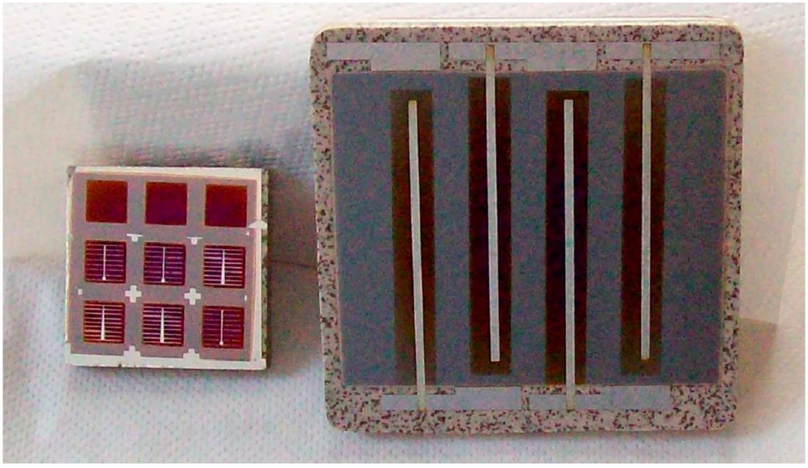

Fig. 1 Prototype of thin-film photovoltaic cell laminated to porcelain tile [1].

Certainly, back-ventilated ceramic tile façade systems offer low environmental impact attributes that have been well documented:

Durability – non-absorptive, nontoxic natural material that can incorporate recycled content. **Water control efficiency** – dissipates and prevents water infiltration with external controls and access; minimise internal wall cavity issues such as mould and effects on indoor air quality. **Energy efficiency** – dissipates of wind and solar heat for improved thermal performance and elimination of thermal bridges with external insulation, convection of air within the wall cavity, good thermal conductivity of tile [9,10,11]. **Life-cycle efficiency** – durability, fire-resistance, ease of maintenance with non-toxic cleaning solutions, ease of replacement/of both ceramic panels and internal wall components. **Construction and post-occupancy efficiency** — reduces construction time; efficiency of maintenance and replacement [1].

2. A SUSTAINABLE SKIN

Contemporary architects internationally are breathing new life into the old tradition of using ceramic elements on exteriors. The results are striking facades that marry expressive ornament with sustainability.

Ornamental, often textured facades – not seen in significant numbers since the floridly decorative ones on Art Nouveau buildings – have made a comeback in recent years. Architects who have helped spearhead this development include London-based FAT, whose Blue House is fronted by a cartoon-like, powder blue silhouette of a house, and Squire & Partners, which has just completed a house in Mayfair whose facade bristles with 4,000, folded aluminium leaves in bronze. Often bespoke, today's ornamental facades make a virtue of craftsmanship. And usually made of a single material, they tend to be monolithic yet avoid being dull since they are unique and eccentric.

One tributary of the trend is a growing number of buildings with large-scale, matt or glossy ceramic facades. These inevitably recall such elaborately decorated Art Nouveau buildings as Antoni Gaudí's Casa Batlló with its iridescent roof, Paris's Ceramic Hotel with its glazed earthenware facade, courtesy of ceramicist Alexandre Bigot, and Villa Marie-Mirande in Brussels, which is cloaked with hand-made tiles provided by ceramicist Guillaume Janssens [12].

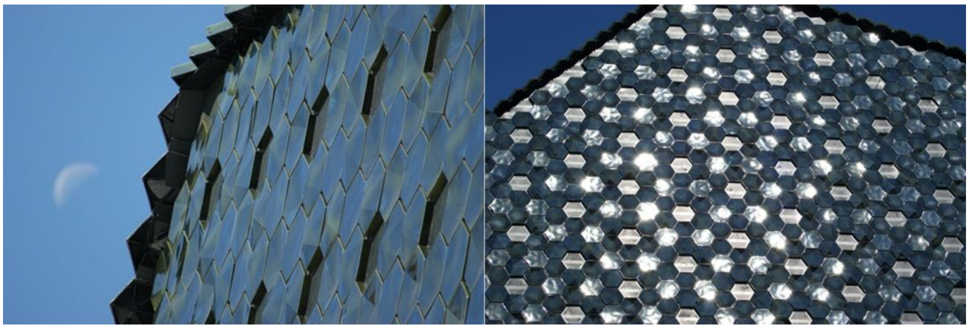

Fig. 2 Herzog & de Meuron has added a new roof to Basel's Museum der Kulturen, whose 3D tiles animate it, especially in strong sunlight. The steeply angled roof deliberately echoes the rooflines of the surrounding medieval buildings [12].

Today's architects who create ceramic facades are aware of these traditions. But their versions differ from Art Nouveau buildings in that they marry the potentially decorative quality of ceramic tiles with a contemporary, relatively minimalist aesthetic and boldly sculptural, abstract forms. And architects today often refer to local context. Take Herzog & de Meuron's renovated Museum der Kulturen in Basel of 2011. Now housing ethnographic artefacts, it was originally designed in 1849 by Melchior Berri, with an extension added by architects Vischer & Söhne in 1917. By the Noughties, it boasted 30,000 objects, and more space was needed. Enter Herzog & de Meuron, which crowned it with a new, double-height gallery floor whose cantilevered roof is clad in a striking, virtually windowless carapace of hexagonal, ceramic tiles in a stormy grey colour reminiscent of the inside of mussel shells. Its convex, concave and flat tiles – supplied by German architectural ceramics specialist Agrob Buchtal – create a 3D surface, and so enhance the sculptural quality of the roof. The tiles also animate the roof's surface when they sparkle in sunlight. What's more, the roof's jagged, asymmetric silhouette evokes a Gothic fairytale but its form isn't arbitrary or merely fanciful: it's designed to echo the roofs of the surrounding medieval buildings, figure 2. [12].

Fig. 3 The white faience facade fronting One Eagle Place, in London's Piccadilly, is adorned with a jazzy ceramic cornice by artist Richard Deacon and red window reveals; photos Dirk Lindner [12].

Fig. 4 One Eagle Place's interior overlooks Piccadilly's flickering LED signs. The idea is that the latter are reflected on the building's white faience facade; photo Dirk Lindner [12].

Fig. 5 One Eagle Place's interior overlooks Piccadilly's flickering LED signs. The idea is that the latter are reflected on the building's white faience facade; photo Dirk Lindner [12].

A passion for ceramics and craftsmanship is central to the workshop of Toni Cumella, a ceramicist who, between 1989 and 1992, helped restore Gaudi's Casa Battló and Parc Güell. Called Ceràmica Cumella and based near Barcelona, the workshop has also collaborated on many cutting-edge architectural projects, notably architects Enric Miralles and Benedetta Tagliabue's spectacular Santa Caterina food market of 2005 whose undulating roof is carpeted with 325,000 tiles. And Cumella has provided the ceramic lattice on two walls enveloping the CEIP primary school at Cornellà de

Fig. 6. Tiles in seven, subtle shades of white, also provided by Toni Cumella, clad a building designed by architect Pedro Campos Costa – a new addition to the existing Lisbon Oceanarium [12].

Llobregat, near Barcelona, of 2010, designed by Mestura Arquitectes. Its ceramic components have angular facets, which, facing one direction, are coated with a warm, red glaze and, facing the opposite way, with a cool, green glaze – and provide a glass box encasing the building's interior with shade, figure 5[12]. Tiles in seven, subtle shades of white, also provided by Toni Cumella, clad a building designed by architect Pedro Campos Costa – a new addition to the existing Lisbon Oceanarium, figure 6. [12].

3. ANTI-MICROBIAL GLAZE "RAK CERAMICS" [13]

What is Anti-Microbial Glaze? Anti-Microbial Glaze inhibits the growth of microbes and reduces micro bacterial contamination. It contributes in creating a much healthier living and working environment. In wet areas, bacteria spreads fast and products with Anti Microbial Glaze can help in creating a healthier environment[13].

Where should one use products with the Anti-Microbial Glaze? In several countries around the world where hygiene standards are very high, usage of tiles with specialised glazes or coatings are made mandatory in places such as hospitals, clinics, laboratories and pharmaceutical industries. Besides these locations, tiles and sanitaryware with RAK Anti-Microbial glaze can be used in schools, hotels, catering institutions, creches, and even in homes. Many consultants around the world are already specifying products with Anti-Microbial glaze for a lot of locations as those mentioned earlier, where they think health is of high concern to their clients or to the would be inhabitants, figure 7 [13].

Technical Specifications for RAK Antimicrobial

Description	Length and Width	Thickness	Straightness of sides	Rectangularity	Surface Flatness	Water Absorption	Breaking Strength	Modulus of Rupture	Resistance to Surface Abrasion	Thermal Shock Resistance	Crazing Resistance	Resistance to Chemicals	Resistance to Stains
Test Method	BS EN ISO 10545-2	BS EN ISO 10545-2	BS EN ISO 10545-2	BS EN ISO 10545-2	BS EN ISO 10545-2	BS EN ISO 10545-3	BS EN ISO 10545-4	BS EN ISO 10545-4	BS EN ISO 10545-7	BS EN ISO 10545-9	BS EN ISO 10545-11	BS EN ISO 10545-13	BS EN ISO 10545-14
International Standard	±0.5%	±10%	±0.3%	±0.5%	+0.5% −0.3%	> 10%	≥600N	≥15N/mm^2	Manufacturer to state abrasion class	no visible defect	no crazing	no visible effect	Manufacturer to state class
RAK Ceramics Specification	±0.3%	± 5%	±0.3%	±0.4%	±0.3%	10-17%	≥700N	≥18N/mm^2	PEI Class 4	no visible defect	no crazing	no visible effect	Stains removed Min. Class 4

Fig. 7 Tehnical specifications for RAK antimicrobial [13]

When is the Anti- Microbial Glaze incorporated during production? This specialised glaze is incorporated into the glaze on the tile, during the manufacturing of the tile. The firing of the glaze into the tile at high temperatures creates a surface that inhabits the growth of microbes that come in contact with the tile[13].

Will the Anti-Microbial Glaze wear off over a period of time? No. Since it is merged with the glaze on the tile, the glaze is close to being permanent [13].

Which tiles RAK Ceramics sells with the Anti-Microbial Glaze? RAK Ceramics offers glazed tiles in a wide range of sizes and finishes with the Anti-Microbial Glaze. Initially, plain coloured- ceramic white body and porcelain body tiles will be offered with this glaze.

Can I specify the tile models and the sizes in which I need the Anti-Microbial Glaze? RAK Ceramics will offer a wide range of tiles in different sizes with this glaze. In case of project orders for hospitals, schools, hotels, pharmaceutical factories etc., RAK Ceramics will consider the customer requests to make any specific tiles within its wide range of glazed tiles, with the Anti-Microbial Glaze incorporated [13].

How much more do the tiles with Anti-Microbial Glaze cost over the normal ones? The tiles with this glaze will cost a premium over the regular models. This premium will depend upon the order quantum for project orders. The premium on any tiles with this glaze is certainly 'value for money' considering the many benefits such tiles provide the user. As a guideline, the additional cost for tiles with this glaze will be Euro 3 per sq.mt. over the normal price of the tile [13].

Have the tiles with this type of glaze being approved in laboratories? Yes, the tiles with the special glaze have been tested in Europe & in the UAE in independent institutions. Even after incubation with microbes for several hours / days the tiles tested did not retain the microbes [13].

Can the tiles with this glaze be used in the exteriors of buildings? Yes, these tiles can be used in the exteriors as well [13].

Does the glaze affect the finish of the tiles? No, as the tile manufacturing process itself is not altered, neither the finish and the look of the tile is affected, nor are any of its other original properties

Do you offer floor tiles with this glaze as well? Yes, with the specialised chemical components in the glaze and the special technology of firing the glaze at high temperatures, we can offer both wall tiles and floor tiles with this glaze [13].

How do I clean the tiles with this glaze? The same way as you will clean regular ceramic or porcelain tiles. As in the case of any ceramic or porcelain tiles, you should avoid using any sharp abrasive material for cleaning the tiles. Using clear warm water or a neutral cleaner specific to ceramic tiles, you can clean these tiles [13].

What about the grouts for such tiles? You can use normal grouts for filling the joints in tiling. We however recommend LATAPOXY SP- 100 Epoxy Grout which due to its physical nature does not allow the mold to take root. In case cementitious grout is used, we recommend the use of LATICRETE 1776 Grout Admix with anti microbial additives which inhibits growth of bacteria and mold in the grout joint [13].

4. Illuminating Through Ceramics

“Illuminating Through Ceramics” the exhibition which showed the exciting potential for the use of ceramics – clays, glasses and concretes – for light redirection on contemporary facades. This exhibition adds greatly to understanding of the use of these techniques for both light redirection and visual expression of a facade. The various ceramic lattice wall systems promulgated in this exhibition, on the other hand, potentially offer controllable daylight distribution of varied patterns, good colour properties and privacy/view but with minimal impact of the interior of a building. The exhibition demonstrates that ceramic lattice walls offer daylight guidance that not only provides dynamic control of light but is also capable of enhancing the facade of a building [14].

4.1. Modular light-shelves
David Parry, Jason Stewart, Katherine

The double facade incorporates external ceramic elements that act as modular light-shelves. The angled surface of the top of the shelves helps to redirect light into the internal spaces. The array of different angled surfaces in conjunction with the diverse dimensions of the ceramic pieces prevent a one dimensional light display occurring. Furthermore, the use of different coloured reflective glazes gives a more playful aesthetic to the facade, which breaks up what would otherwise be an expanse of curtain glazing. It also provides a colourful phenomenon in the interior of the building. Light studies have been produced to create a profile that allows for a powerful penetration of natural daylight figure 8. [14].

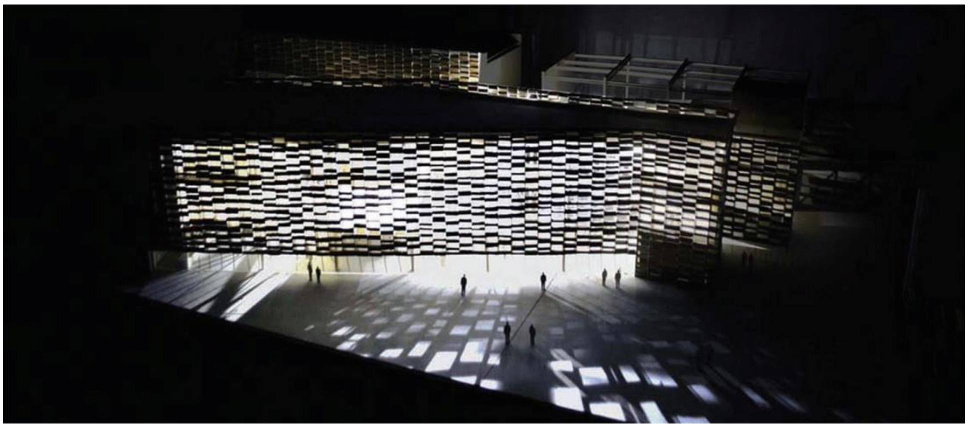

Fig. 8 Modular light-shelves David Parry, Jason Stewart, Katherine Strange[14]

4.2. Ceramic lanterns
Amy Ellis-Taylor, Emma Smith, John Watling [14]

This project proposes the use of ceramic clad 'pods' hanging in the atrium space. These pods act as student 'break-out' spaces, for study or teaching. The ceramic louvres clad the whole envelope of these pods, and are backlit with an array of coloured LED's that filter and project the internal light towards the open environment of the atrium. The screened light here is used as a means to show occupancy as well as to provide a powerful articulated atrium with the image of the ceramic lanterns 'floating' in the space, figure 9.

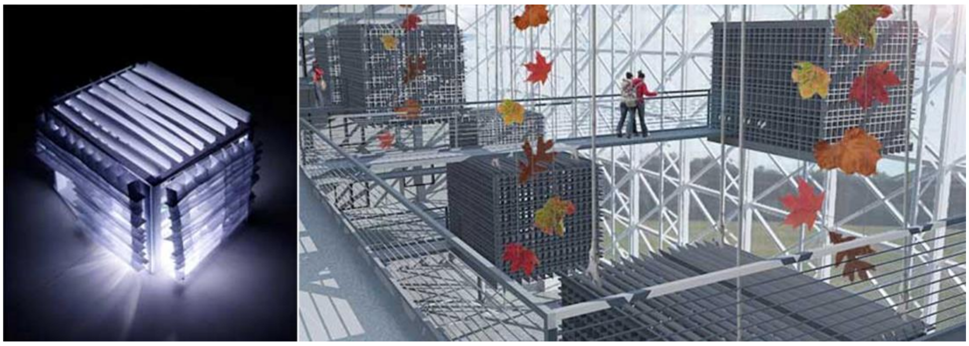

Fig. 9 Ceramic lanterns Amy Ellis-Taylor, Emma Smith, John Watling [14].

4.3. Hydroponic chandelier ceramic lanterns Loren Durkin, Adrian Lombardo, Zara Moon [14]

The Hydroponic Chandelier is a complex organic structure forming a ceramic tubular chandelier that distributes light and captures and channels rainwater, which allows the growth of plants thanks to a hydroponic system. The daylight is filtered and reflected down the ceramic surfaces, the falling water, and the translucent leaves of the plants, creating a sophisticated light-pipe that projects constantly-changing light patterns in the courtyard of the building, figure 10a,10b. [14]

Fig. 10a Hydroponic Chandelier Loren Durkin, Adrian Lombardo, Zara Moon [14].

Fig. 10b Hydroponic Chandelier Loren Durkin, Adrian Lombardo, Zara Moon [14].

4.4. Adaptable ceramic shading, Jenna Fife, Georgina Holden, Robert Novelli [14]

The Adaptable Ceramic Shading forms part of the buildings geodesic roof, as an integral environmental strategy that combines several technologies. The rational grid of the roof's structure allowed for a tiling pattern to admit light that floods into the building in a dynamic fashion. The array of reflective and translucent ceramic tiles, combined with transparent glazed panels creates a wide range of lighting patterns that change with the movement of the sun, figure 11.[14].

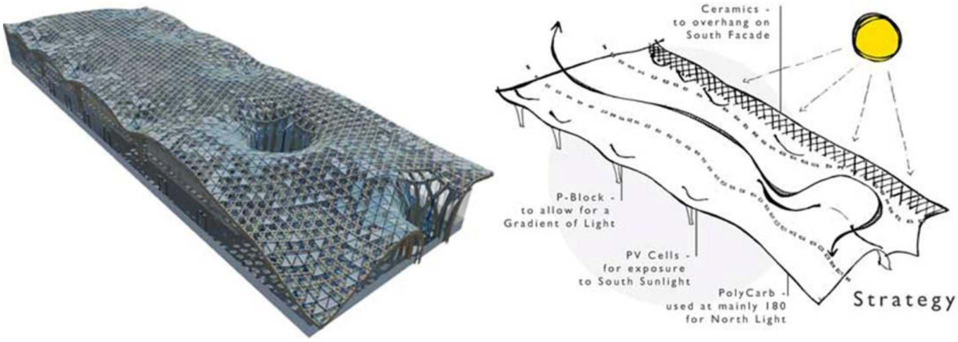

Fig. 11 Adaptable Ceramic Shading, Jenna Fife, Georgina Holden, Robert Novelli [8].

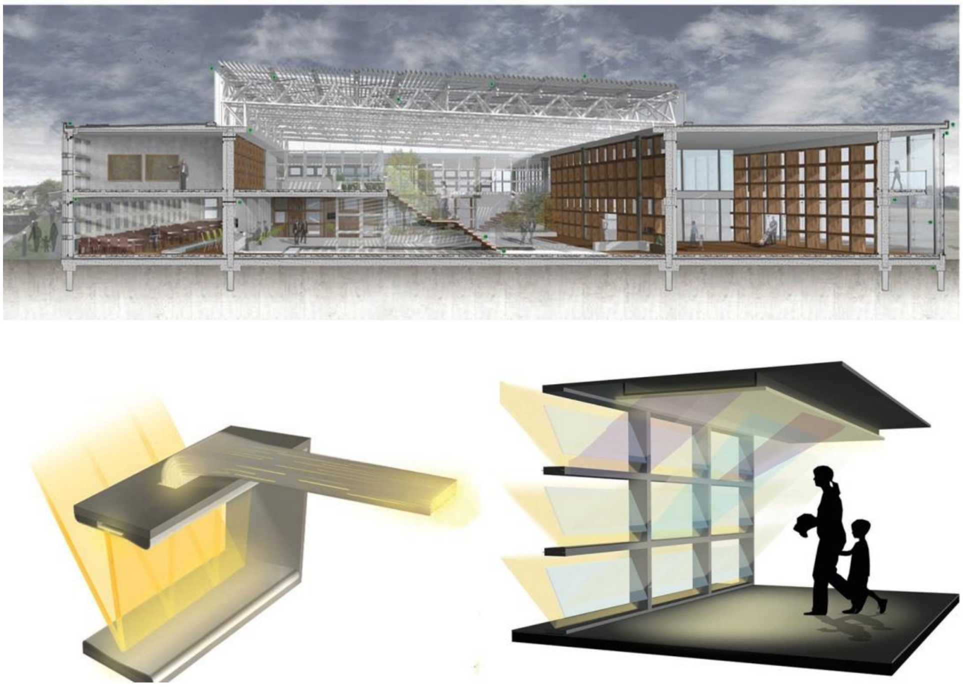

Fig. 12 Lighting surfaces Serena Cardozo, Ryan Jones, Li Yin Lim [14].

4.5. Lighting surfaces
Serena Cardozo, Ryan Jones, Li Yin Lim [14]

The rational facade of the building contains ceramic components with a prismatic surface that captures and reflects light into the interior spaces. The ceramic reflective surfaces are strategically inserted on the transoms and mullions of the glazing. Once the daylight is inside, reflective panels on the interior ceilings help to distribute light further into the building, producing a bright day lit interior, figure 12. [14].

5. CONCLUSIONS

The potential of ceramic claddings in the design of urban spaces, is their socio-economic, cultural and ecological sustainability: socio-economic, through the creation of local employment and prosperity; cultural, through the preservation of operational processes and traditions; and ecological, as a means to protect the equilibrium of the ecosystem, associated with its aesthetic and emotional potential, closely linked to its chromatic richness.

Ceramic tile in future architecture, given both the promising innovations and solving certain technical issues over the past 10 years, seems to remain well positioned to become one of the most important sustainable architectural materials in the 21st century…as true perfection of art and science in the minds of most architects and engineers. If the tile industry can continue its legacy of product innovation, resolve urgent technical issues for architects and end-users, and adapt to the changing architectural paradigm of building materials as integrated systems and not individual products, that will proclaim ceramic tile cladding systems as one of the most significant developments in sustainable architecture in the past years.

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REFERENCES

1. Ceramic tile on the forefront of architecture, A 10 Year Retrospective words: Richard P. Goldberg AIA, CSI, NCARB, Architect – Professional Consultants International, LLC (PROCON)
2. K. Okada, Lotus ceramicks for counteracing urban heat island efefects, Eco – efficient materials for mitigating building cooling needs, 2015, Pages 195–213
3. http://www.floornature.com/architecture-materials/sustainable-architecture-from-design-to-ceramic-coverings-9980/
4. Russo, M., Borkey, P., Cubel, E., Lévêque, F., Maas, F., Local sustainability and competitiveness: the case of the ceramic tile industry, European Foundation for the Improvement of Living and Working Conditions. Retrieved August 15, 2010, from http:// www.eurofund.europa.eu/pubdocs/1998/32/en/1/
5. Carter, C., Norton. M., "Ceramic Materials | Science and Engineering", Springer, 2007
6. Ceramic Tiles: A Sustainable Architectural Skin, Carla LOBO, Colour and Light in Architecture_First International Conference 2010_Proceedings,p.p.354/359
7. Fairman, H., Hemmendinger, H. "Stability of Ceramic Reflectance Standards Color", Color Research and Application, 23(6), 1998, pp.408-415.

8. Xingxing Zhang, Jingchun Shen, Yan Lu, Wei He, Peng Xu , Xudong Zhao, Zhongzhu Qiu, Zishang Zhu, Jinzhi Zhou, Xiaoqiang Dong,Active Solar Thermal Facades (ASTFs): From concept, application to research questions, Renewable and Sustainable Energy Reviews 50 (2015) 32–63
9. Baolong Han, Rusong Wang, Liang Yao, Hongxiao Liu, Zhonghang Wang, Life cycle assessment of ceramic façade material and its comparative analysis with three other common façade materials, Journal of Cleaner Production 99 (2015) 86-93
10. Ecem Edis, Ines Flores-Colen, Jorge de Brito, Quasi-quantitative infrared thermographic detection of moisture variation in facades with adhered ceramic cladding using principal component analysis, Building and Environment 94 (2015) 97e108
11. Ecem Edis,Inês Flores-Colen,Jorge De Brito, Time-Dependent Passive Building Thermography for Detecting Delamination of Adhered Ceramic Cladding, Journal of Nondestructive Evaluation (2015)
12. http://www.architonic.com/ntsht/out-on-the-tiles-ceramic-architectural-facades/7000794
13. http://www.rakceramics.com/catalogs/Speciality-Tiles-Catalog/RAK-Antimicrobial.pdf
14. Rosa Urbano Gutierrez, Illuminating Through Ceramics, Lecturer in Architecture and Environmental Design, First published 2013, Published by Liverpool School of Architecture

KERAMIČKE FASADNE OBLOGE KAO ELEMENT ODRŽIVOG RAZVOJA

Građenje u skladu sa prirodom, ima mali uticaj na životno okruženje, a zadovoljava osnovne potrebe stanovništva. Zelena arhitektura je grana arhitekture koja obuhvata radnje planiranja, dizajniranja i gradnje različitih vrsta objekata uz što manji efekat na životnu sredinu. Izgradnja takozvnih "zelenih objekata" je u skladu sa pojmom o održivosti i pokušava da uravnoteži ekološke, ekonomske i socijalne potrebe. U izgradnji objekata ovog tipa, koriste se ekološki ispravni materijali, koji u svojoj proizvodnji, primeni i raspodeli u što manjoj meri zagađuju zalihe vode, zemljišta i vazduha u okruženju. Što su građevinski materijali korišćeni za izgradnju više održivi, to je više održiva i zgrada, a i njeno funkcionisanje sa obnovljivim izvorima energije. U radu su razmatrani keramički fasadni elementi, tj. obloga. Primenom keramičkih fasadnih obloga dobija se veća percepcija urbane sredine čime naši životi dobijaju nove senzualne i vizuelne kvalitete uz ispunjenje uslova zelene gradnje.

Ključne reči: *održivost, zelena grdnja, materijali, keramička fasadna obloga*