JSACE 1/37

Exploring Light Permeability of Rammed Earth Blocks with Recycled Glass

Received 2024/04/22

Accepted after revision 2024/12/11

Exploring Light Permeability of Rammed Earth Blocks with Recycled Glass

Mehmet Onur Senem*, Salih Özdemir, Orkan Zeynel Güzelci, Sema Alaçam

Faculty of Architecture, Istanbul Technical University,
Taşkışla Cd. No:2, 34367 Şişli/İstanbul, Türkiye

*Corresponding author: **senem19@itu.edu.tr**

https://doi.org/10.5755/j01.sace.37.1.37037

Abstract

This study aims to address the environmental issues arising from traditional building materials such as concrete and steel by introducing a building unit that combines rammed earth with recycled glass. The use of glass alongside earth aims to enhance illumination levels and light permeability in interiors without using conventional building components like doors or windows. The scope includes fabricating blocks with varying hollow and glass material ratios to measure their light transmittance capacities. A setup involving a light source, an earthen block, and a lux meter is developed to calculate light transmittance for both non-filled and glass-filled blocks. Results indicate that when the developed unit is used to produce a wall, it can provide illumination levels from 750 to 34,500 lux in interior spaces.

Keywords: sustainability; traditional building materials; rammed earth; recycled glass; light permeability.

Introduction

In the context of climate change, where the Architecture, Engineering, and Construction (AEC) sector's dominant use of concrete and steel contributes to nearly 40 percent of the world's CO2 emissions, there is an urgent need for sustainable and low-carbon footprint materials. Consequently, materials offering low environmental impact and energy-efficient solutions have gained importance. Earth, a locally available and traditional material, stands out for its compression resistance, high thermal inertia, direct use of excavated soil, non-waste production, and reusability (Agustí-Juan & Habert, 2017; Krezlik et al., 2021; Porter et al., 2018; Sousa et al. 2022).

The utilization of stabilized rammed earth as a construction material, one of the earthen materials, holds considerable potential for environmentally friendly and affordable solutions. Due to their technical specifications and notably thick walls (Ben-Alon et al., 2020), earthen structures typically feature low illuminance levels in their interior spaces. While numerous studies in this domain have examined the structural behavior, material properties, thermal comfort performance, and user satisfaction related to rammed earth building blocks (Avila et al., 2021), a gap concerning light transmittance remains in the literature.

The primary goal of this study is to design and fabricate a building block (unit) that increases illuminance within the interior spaces of rammed earth structures. Another objective is to determine the capabilities of an envelope system, consisting of these developed blocks, in terms of daylight transmittance. In this context, the study seeks to answer the following research questions:

- Can a solid material (rammed earth) effectively work with a translucent material (glass) in the fabrication of a building block?
- Is there a noticeable quantitative relationship between the amount of glass in the fabricated building blocks and the amount of light transmitted?

ktu 1922

Journal of Sustainable Architecture and Civil Engineering
Vol. 1 / No. 37 / 2025
pp. 76-83
DOI 10.5755/j01.sace.37.1.37037

Within the scope of this study, rammed earth blocks are created with varying numbers of cavities: none, one, two, three, and four. Subsequently, these cavities are filled with recycled glass. Since there are no prior studies or examples, establishing the successful fabrication of a building block combining rammed earth and glass is set as a criterion for success. Additionally, determining the light transmission levels of the blocks through measurements is essential for evaluations.

Background

This section provides background on rammed earth, light-transmitting concrete, and cobogo. Within the scope of this study, rammed earth is utilized as the main material, with a focus on enhancing its light transmission capabilities. Cobogo, known for its openings that allow light to pass through, is introduced as an architectural element serving as an inspiration for this research.

Rammed earth

Rammed earth is a building technique with numerous advantages in terms of sustainability, energy efficiency, durability, and health. Considering these advantages, renowned architects such as Foster + Partners (2018), Renzo Piano Building Workshop (2020), and Francis Kéré (Fernández-Galiano, 2018) have focused on earthen materials to construct architectural components or entire buildings.

Rammed earth is a sustainable building material due to its low embodied energy, low carbon footprint, natural origin, and low transportation costs (Shaikh, 2014). Moreover, its high thermal mass helps maintain warm interiors in summer and protects against cold in winter. These features enable rammed earth to provide energy-efficient architectural solutions (Preciado & Santos, 2020).

As a natural material not subjected to various chemical processes, rammed earth supports the creation of healthy indoor environments (da Rocha et al., 2014). In terms of durability, rammed earth is highly durable when used with appropriate stabilization techniques and binding materials such as cement (Porter et al., 2018). Another important feature of rammed earth is its natural fire resistance (Giuffrida et al., 2021).

Light transmitting concrete

Research is being conducted in fields such as materials science and architecture to make solid materials transparent. In particular, various approaches are being pursued to provide light-transmitting capabilities to concrete, which is known for its durability and opacity. This structural building material, enhanced with new features, is referred to as light-transmitting concrete, translucent concrete, or transparent concrete (Luhar et al., 2021). Light-transmitting concrete, widely used in applications such as walls, allows sunlight to penetrate interior spaces, thereby increasing illumination levels (Roye, 2013). Furthermore, such walls aim to minimize the energy required to achieve intended illumination levels in interiors (Zielińska & Ciesielski 2017).

To add transparency to concrete, optical fibers (Bhushan et al., 2013) or polyester resin (Juan & Zhi, 2019) are generally used as light-guiding elements. In their study, Henriques et al. (2020) observed that when the optical fiber ratio in transparent concrete increased from 3.5 percent to 5 percent, the light transmittance of the concrete increased by 100 percent.

Concrete is expected to exhibit high durability levels. Luhar and Khandelwal (2015) noted that the compressive strength of transparent concrete (36.70 MPa) nearly matched that of ordinary concrete (39.50 MPa). In addition to its advantages in structural and energy efficiency, transparent concrete is also used for aesthetic purposes.

Cobogo

Cobogo bricks originated in Brazil in the early 20th century. Cobogo is a hollow architectural element designed for partitions or screens, providing controlled light and ventilation. Initially, cobogo designs aimed to ensure light and air permeability with bricks featuring regular and uniform openings. Available in various shapes and patterns, cobogo bricks are made from materials such as concrete and ceramics (Rytel, 2013). The use of cobogo bricks enhances structures both environmentally and aesthetically (Araujo, 2019). The main reason why cobogo originated in Brazil is to prevent overheating and excessive sun exposure in interiors, caused by the variable climate (Rytel, 2013).

Current studies on cobogo generally proceed through computational design processes and digital fabrication. Teixeira et al. (2015) presented a parametric modeling system for cobogo alternatives aimed at providing privacy and visual permeability. Fagundes et al. (2018) analyzed a physical cobogo unit and a digitally modeled version of the same cobogo in terms of visuality and light transmittance. Another study aimed to increase the energy efficiency of cobogo and improve thermal performance through material computation (Santana Neto & Silva, 2016). Natividade (2018) presented the methods and results of a workshop investigating the design and manufacturing of facade elements through computer-aided design and manufacturing techniques. At the workshop, cobogo was chosen as the element to create, taking into account both environmental factors and budget. Concrete was selected as the material due to its plasticity. Caetano et al. (2020) focused on a facade design using cobogo bricks. They not only explored geometries but also worked to develop, rationalize, and produce design solutions. Instead of a single type, Caetano et al. (2020) worked with different bricks to create various facade alternatives that would meet the intended design. In summary, cobogo offers insights through its light transmission capabilities and related energy efficiency efforts.

Case Study

This section presents the experimental setup and outcomes of experiments aimed at producing blocks composed of multiple materials. Additionally, it provides numerical results concerning the light transmittance properties and an analysis of the findings.

Experimental setup

Earth and recycled glass were chosen as the primary materials for the blocks, with cement serving as the binding material and metal used to fabricate the mold. The outer formwork for ramming the earth was constructed using four metal plates, each measuring 10x10 cm and 2 mm thick. These plates were assembled into a cube-shaped mold, with the top and bottom faces left open. The inner formwork was created by cutting a metal pipe with a diameter of 2 cm into 10 cm lengths to accommodate the glass. The earth to be rammed inside the mold was sourced from a depth of 60 cm below ground level, and pourable-quality glass was selected. A darkroom, an opaque tunnel, a light source, and a device to measure illuminance levels were required to conduct the light transmission test on the fabricated blocks.

Experiments and results

In the context of rammed earth construction, various studies have investigated the strength and characteristics of the material in relation to the mixtures used. For instance, Easton (1982) reported beneficial results using a 10% cement mixture. Jayasingh and Kamaladasa (2007) introduced the term “cement stabilized rammed earth” and demonstrated that incorporating 6% or more cement in the mixture significantly enhances the compressive strength and overall structural integrity of rammed earth. Kariyawasam and Jayasinghe (2016) mixed different soil types with 6%, 8%, and 10% cement to evaluate the material’s compressive strength and durability, finding that the 10% cement mixture produced the best results.

Building on these findings, the earth was sourced from at least 60 cm below the ground, sifted to remove gravel (Fig. 1a), and a dry mixture was prepared with 10 parts of cement for every 100 parts of soil (Fig. 1b). Water was poured into the dry mixture using the drip method and mixed (Fig. 1c, Fig. 1d). After oiling both parts, the cylindrical inner mold was placed inside the cubic outer mold

(Fig. 1e, Fig. 1f, Fig. 1g). The mixture was placed in the remaining volumes, leaving the inner mold empty, and rammed using a tamper. The ramming process was carried out gradually and repeatedly to ensure the earth was fully stabilized (Fig. 1h, Fig. 1i). After 30 minutes, both the cubic and cylindrical molds were dismantled, and the earth block was obtained (Fig. 1j, Fig. 1k). In the next stage, recycled borosilicate glass was melted at 1400 degrees Celsius and poured into the volume where the cylindrical mold had been removed. Before obtaining the final blocks, the cooled glass material was kept in the cooling oven at 600 degrees Celsius for 1 hour to prevent cracks from forming (Fig. 1l, Fig. 1m). This process was repeated by adding two, three, and four inner molds into the outer mold, respectively. As a result, four rammed-earth blocks with light-transmittance properties were produced (Fig. 1n, Fig. 1o, Fig. 1p). However, the blocks containing two and four holes cracked during the glass pouring process due to extreme temperatures.

Fig. 1

Block fabrication process

Before initiating the light permeability test, the physical and mechanical properties of the blocks were evaluated. This assessment included calculating the density of both samples. For the hollow block (first sample), which contained a cylindrical void (diameter: 2 cm, height: 10 cm), the soil density was calculated as 1.781 g/cm^3 (Fig. 2a). For the glass-filled block (second sample), which used borosilicate glass with a density of 2.5 g/cm^3 to fill the same cylindrical void, the soil density was found to be 1.946 g/cm^3 after accounting for the mass of the glass filling (Fig. 2b). Additionally, a compression test was conducted on a solid block, which demonstrated a load-bearing capacity of 1.8 MPa (Fig. 2c; Fig. 2d). To mitigate water permeability, a resin-based coating was applied to the block surfaces.

Fig. 2

Weight measurement and compression test of blocks

Following the production of the units, a light-impermeable tunnel was constructed using 5mm-thick foam board, with two openings on opposite faces of the tunnel. One opening was for the light source, to direct light onto the earthen block, and the other was for the placement of the lux meter. In this setup, a halogen lamp with a capacity of 1300 lux was used as the light source (Fig. 3a). In a completely dark environment, a measurement was first conducted with the tunnel empty (Fig. 3b, Fig. 3e). Subsequently, the fabricated blocks—both non-filled and glass-filled, each with a single hole—were placed in the tunnel to measure the illuminance levels (Fig. 3c, Fig. 3d, Fig. 3f, Fig. 3g, Fig. 3h).

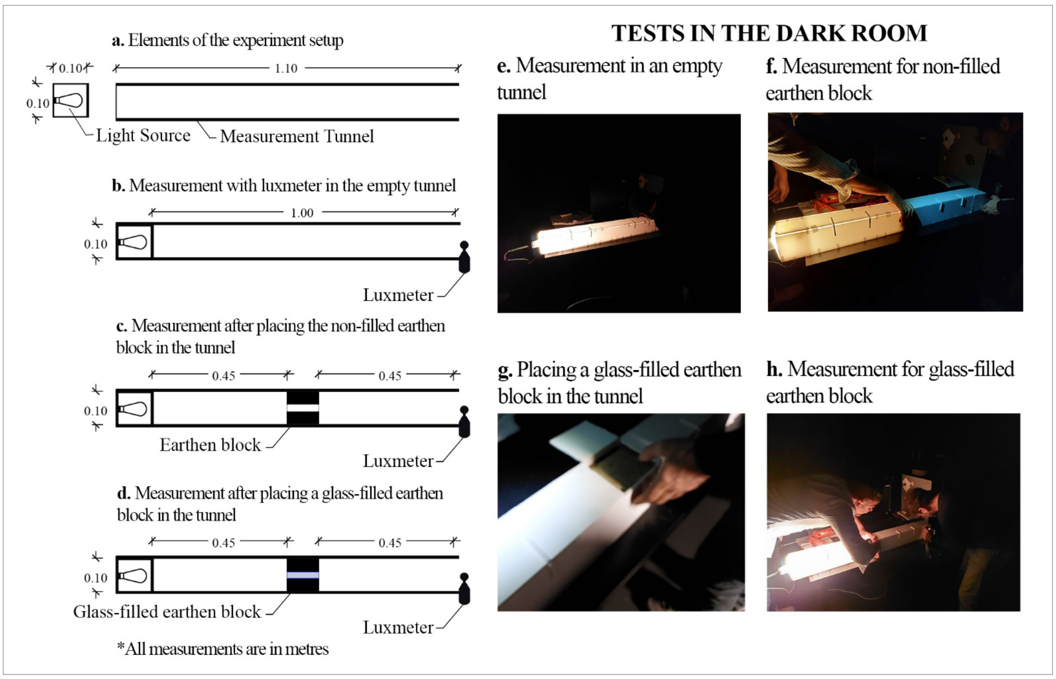

Fig. 3

Experiment setup and measurements

Findings

The durability evaluation of the produced blocks revealed that the spaces left in a grid pattern weakened the material's strength, resulting in cracks due to the heat from the poured glass (Fig. 4b, Fig. 4f, Fig. 4d, Fig. 4h). Furthermore, the block containing three holes and filled with glass was damaged during the light transmission tests, due to multiple transports between laboratories (Fig. 4c, Fig. 4g).

Since there are no established guidelines or standards for examining the light-transmission property of these blocks, evaluating their success against such standards was not possible. However, reliable numerical results were obtained; the block with a single hole transmitted an illuminance of 23 lux (Fig. 4a), while the block filled with glass in the same configuration transmitted only 0.5 lux (Fig. 4e).

For a wall measuring five meters in length and three meters in height, approximately 1,500 blocks would be required. In this scenario, if every block with an empty hole transmits 23 lux and every glass-filled block transmits 0.5 lux, the interior could achieve illuminance levels ranging from 750 lux to 34,500 lux.

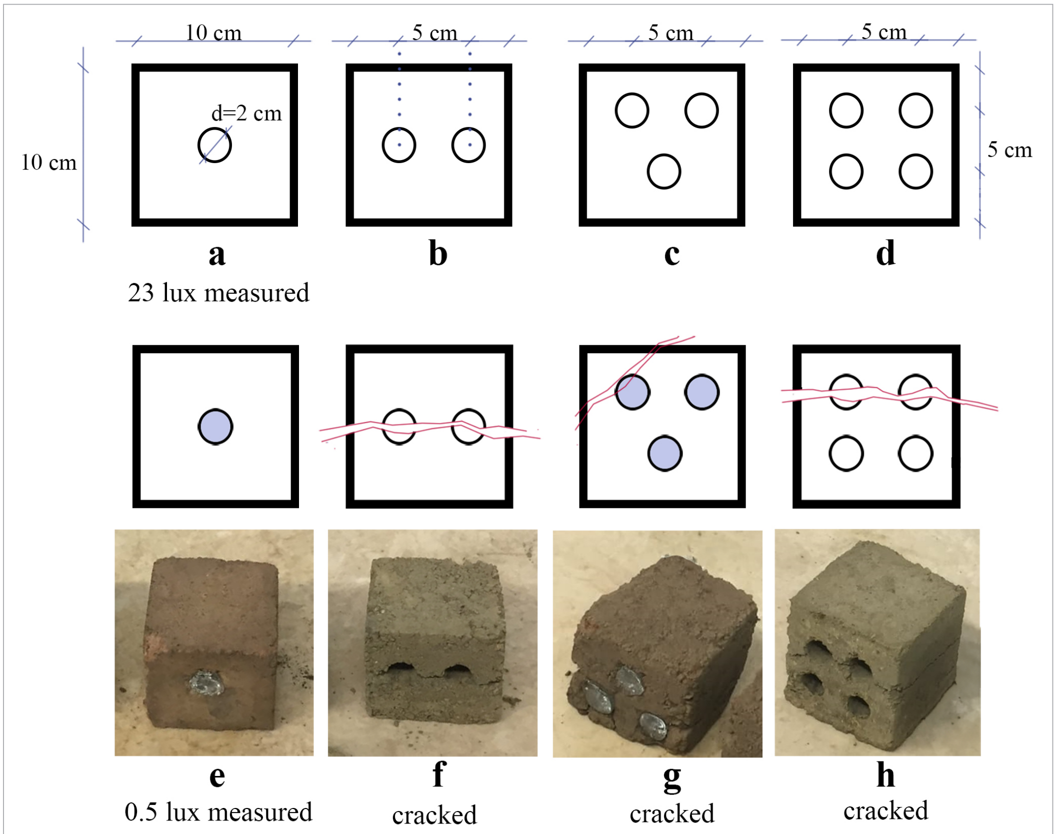

Fig. 4
Fabricated blocks and measurement results

Conclusions

This study introduces a methodology aimed at contributing to the development of materials in the realm of sustainable fabrication. The results of this study offer valuable insights into the potential of integrating recycled glass into rammed earth blocks to enhance light permeability while maintaining structural integrity. The experiments conducted reveal both the possibilities and the challenges associated with this innovative approach.

However, the study has two critical limitations. The primary limitation is that blocks with multiple hollows cracked during both the glass pouring and transportation phases. As a result, the relationship between the increase in the number of hollows or glass-filled hollows within the earthen block and light transmissibility could not be examined. Future research aims to address this issue by fabricating larger-sized blocks, which will allow for experiments on hollow geometry, pattern, and the number of hollows.

Another limitation is the requirement for a well-equipped workshop environment to conduct the glass pouring process. Pouring glass into the hollows within the blocks is quite challenging in areas lacking the necessary infrastructure and those far from urban centers. Future studies will focus on procuring and applying materials that facilitate light transmission. Specifically, these studies will explore the use of resin materials, assessing their sustainability.

Furthermore, the study did not consider factors such as the angle of sunlight incidence in the design of block openings. Therefore, upcoming studies aim to use computational models to simulate and optimize the light transmissibility of the units.

Acknowlegement

The authors would like to express their gratitude to Yusuf Öbelik from Efe Glass for his assistance duringthe glass pouring phase, as well as Emre Erkin and Mustafa Berker Yurtseven from the ITU Energy Institute for their guidance throughout the light transmission tests.

References

Agustí-Juan, I., & Habert, G. (2017). Environmental design guidelines for digital fabrication. Journal of cleaner production, 142, 2780-2791. https://doi.org/10.1016/j.jclepro.2016.10.190

Araujo, N. (2019). New technologies in the study of architecture: Learning by making virtual models and digital fabrication. Proceedings of EDULEARN19 (pp. 1855-1861). IATED. https://doi.org/10.21125/edulearn.2019.0522

Avila, F., Puertas, E., & Gallego, R. (2021). Characterization of the mechanical and physical properties of unstabilized rammed earth: A review. Construction and Building Materials, 270, 121435. https://doi.org/10.1016/j.conbuildmat.2020.121435

Ben-Alon, L., Loftness, V., Harries, K. A., Hameen, E. C. & Bridges, M. (2020). Integrating earthen building materials and methods into mainstream construction. Journal of Green Building, 15(1), 87-106. https://doi.org/10.3992/1943-4618.15.1.87

Bhushan, M. P., Johnson, D., Pasha, M. A. B., & Prasanthi, K. (2013). Optical fibres in the modeling of translucent concrete blocks. International Journal of Engineering Research and Applications, 3(3), 13-17.

Caetano, I., Leitão, A., & Bastos, F. (2020). From Architectural Requirements to Physical Creations: An Algorithmic-based Approach for Façade Design. Journal of Façade Design and Engineering, 8(2), 59-80.

da Rocha, C. G., Consoli, N. C., & Johann, A. D. R. (2014). Greening stabilized rammed earth: devising more sustainable dosages based on strength controlling equations. Journal of Cleaner Production, 66, 19-26. https://doi.org/10.1016/j.jclepro.2013.11.041

Easton, D. (1982). The rammed earth experience. Blue Mountain Press.

Fagundes, C. V. M., Costa, C. D., Silva, F. P. D. & Bruscato, L. M. (2018). Facade hollow brick (cobogó) 3D scanning: natural light admission analysis and comparison with original digital 3D model. Proceedings of the 22nd Conference of the Iberoamerican Society of Digital Graphic (SIGraDi 2018) (pp. 596-601). São Carlos, Brazil. https://doi.org/10.5151/sigradi2018-1677

Fernández-Galiano, L. (2018). Francis Kéré: Practical Aesthetics. Arquitectura Viva SL.

Foster+Partners. (2018). Narbonne's museum of antiquities tops out. https://www.fosterandpartners.com/news/narbonne-s-museum-of-antiquities-tops-out

Giuffrida, G., Caponetto, R., Nocera, F., & Cuomo, M. (2021). Prototyping of a novel rammed earth technology. Sustainability, 13(21), 11948. https://doi.org/10.3390/su132111948

Henriques, T. D. S., Dal Molin, D. C., & Masuero, A. B. (2020). Optical fibers in cementitious composites (LTCM): Analysis and discussion of their influence when randomly arranged. Construction and Building Materials, 244, 118406. https://doi.org/10.1016/j.conbuildmat.2020.118406

Jayasinghe, C., & Kamaladasa, N. (2007). Compressive strength characteristics of cement stabilized rammed earth walls. Construction and Building Materials, 21(11), 1971-1976. https://doi.org/10.1016/j.conbuildmat.2006.05.049

Juan, S., & Zhi, Z. (2019). Preparation and study of resin translucent concrete products. Advances in Civil Engineering, 2019. https://doi.org/10.1155/2019/8196967

Krezlik, A., Güzelci, O. Z. & Sousa, J. P. (2021). Rob-LCA - An assessment method to support environmental sensitive material selection in robotic fabrication. Proceedings of the 39th eCAADe Conference - Volume 1 (pp. 455-464). Novi Sad, Serbia: University of Novi Sad. https://doi.org/10.52842/conf.ecaade.2021.1.455

Kariyawasam, K. K. G. K. D., & Jayasinghe, C. (2016). Cement stabilized rammed earth as a sustainable construction material. Construction and Building Materials,105, 519-527. https://doi.org/10.1016/j.conbuildmat.2015.12.189

Luhar, S. & Khandelwal, U. (2015). Compressive strength of translucent concrete. International Journal of Engineering Sciences & Emerging Technologies, 8(2), 52-54.

Luhar, I., Luhar, S., Savva, P., Theodosiou, A., Petrou, M. F. & Nicolaides, D. (2021). Light transmitting concrete: a review. Buildings, 11(10), 480. https://doi.org/10.3390/buildings11100480

Natividade, V. (2018). Digital Design and Fabrication of Freeform Concrete Blocks - The experience of 'Cobogo Trança'. Proceedings of the 36th eCAADe Conference - Volume 1 (pp. 743-752). Lodz, Poland: Lodz University of Technology. https://doi.org/10.52842/conf.ecaade.2018.1.743

Porter, H., Blake, J., Dhami, N. K., & Mukherjee, A. (2018). Rammed earth blocks with improved multifunctional performance. Cement and Concrete Composites, 92, 36-46. https://doi.org/10.1016/j.cemconcomp.2018.04.013

Preciado, A., & Santos, J. C. (2020). Rammed earth sustainability and durability in seismic areas as a building material. In IOP Conference Series: Earth and Environmental Science (Vol. 410, No. 1, p. 012108). IOP Publishing. https://doi.org/10.1088/1755-1315/410/1/012108

Renzo Piano Building Workshop. (2020). Children's Surgical Hospital. https://www.rpbw.com/project/emergency-childrens-surgery-center

Roye, A. (2013). Intriguing transparency. German Research, 35(3), 11-13. https://doi.org/10.1002/germ.201490000

Rytel, G. (2013). The Influence of Climate on the Forms of Brazilian Modernist Architecture in the Years 1925-1960. Kwartalnik Architektury I Urbanistyki, 4, 57-78.

Santana Neto, E. J. D. & Silva, R. C. D. (2016). Computação material: um estudo sobre a atualização geométrica de elementos vazados na arquitetura. Proceedings of the XXth Congreso de La Sociedad Ibero-Americana de Gráfica Digital (SIGraDi 2016) (pp. 43-49). Buenos Aires, Argentina. https://doi.org/10.5151/despro-sigradi2016-479

Shaikh, M. S. (2014). Stabilization of rammed earth. International journal of research in engineering and technology, 298-303. https://doi.org/10.15623/ijret.2014.0304053

Sousa, J. P., Azambuja Varela, P., Güzelci, O. Z., Lacroix, I., Krezlik, A. & Pimenta, M. (2022). Flying Earth. In Diogo, B. Verissimo, C. (Eds.), Emerging voices on new architectural ecologies (pp. 83-90). Porto, Portugal: Circo de Ideias.

Teixeira, R., Lopes, J. V., Paio, A. & Guerreiro, R. (2015). Modelagem Paramétrica de Muros: permeabilidade visual para urbanidade. Proceedings of the 19th Conference of the Iberoamerican Society of Digital Graphics (SIGraDi 2015)- Volume 2, (pp. 786-791). Florianópolis, SC, Brasil. https://doi.org/10.5151/despro-sigradi2015-sp80006

Zielińska, M. & Ciesielski, A. (2017). Analysis of transparent concrete as an innovative material used in civil engineering. IOP Conference Series: Materials Science and Engineering, 245(2), 022071. https://doi.org/10.1088/1757-899X/245/2/022071

About the authors

MEHMET ONUR SENEM

Guest Lecturer

Istanbul Technical University, Faculty of Architecture, Department of Landscape Architecture

Main research area

Ecological Sustainability, Robotics, and AI

Address

Taşkışla Cd. No:2, 34367 Şişli/İstanbul, Türkiye
E-mail: senem19@itu.edu.tr

SALIH ÖZDEMIR

Lecturer

Istanbul Technical University, Faculty of Architecture, Department of Architecture

Main research area

Robotics, 3D Construction Printing, and AI

Address

Taşkışla Cd. No:2, 34367 Şişli/İstanbul, Türkiye
E-mail: ozdemirsal@itu.edu.tr

ORKAN ZEYNEL GÜZELCI

Associate Professor

Istanbul Technical University, Faculty of Architecture, Department of Interior Architecture

Main research area

Robotic Fabrication, Environmental Performance, and AI

Address

Taşkışla Cd. No:2, 34367 Şişli/İstanbul, Türkiye
E-mail: guzelci@itu.edu.tr

SEMA ALAÇAM

Associate Professor

Istanbul Technical University, Faculty of Architecture, Department of Architecture

Main research area

Earthen Architecture, 3D Construction Printing, and AI

Address

Taşkışla Cd. No:2, 34367 Şişli/İstanbul, Türkiye
E-mail: alacams@itu.edu.tr