# Development of Innovative Construction Systems Based on Natural Stone for Illuminated Architectural Applications

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**Abstract**

The growing interest in the use of natural stone materials in architecture and interior design, together with advances in lighting technologies and intelligent construction systems, has created the need for innovative solutions capable of combining functional, aesthetic, and energy-efficient performance. In this context, the present paper aims to present the results of research focused on the development of innovative construction systems based on the use of onyx, travertine, marble, and other natural stones, integrated with modern lighting and control technologies for premium architectural applications.

The research was conducted within a research and development project and focused on the design, development, and conceptual validation of three innovative construction systems: a backlit façade system, an intelligent illuminated flooring system, and a modular illuminated ceiling system. The adopted methodology included the analysis of existing solutions, the definition of functional requirements, the conceptual design of the construction systems, prototype development, and the evaluation of the technical and functional advantages of the proposed solutions.

The research findings demonstrate the feasibility of integrating natural stone materials with modern lighting systems and modular construction technologies, leading to the development of solutions characterized by high design flexibility, energy efficiency, ease of installation, and adaptability to a wide range of architectural applications. Furthermore, the proposed systems contribute to expanding the use of natural stone materials in architecture and interior design while supporting innovation in the field of intelligent construction systems.

The main contribution of this research lies in the development of an integrated approach to innovative construction systems that capitalize on the aesthetic and functional properties of onyx, travertine, marble, and other natural stones through the integration of advanced lighting technologies and modular structural solutions. The proposed approach offers significant potential for application in high-end architectural and interior design projects requiring superior quality, customization, and aesthetic performance.

**Keywords**: innovative construction systems; onyx; travertine; marble; natural stone; architectural lighting; intelligent façades; interior design; research and development.

## 1. Introduction

In recent years, the development of innovative materials and construction systems has become one of the main research directions in the fields of construction and architecture, driven by increasing demands for energy efficiency, sustainability, design flexibility, and enhanced quality of the built environment. At the same time, contemporary architectural trends increasingly emphasize the integration of natural stone materials with advanced lighting and control technologies to create solutions that simultaneously satisfy functional, aesthetic, and technological requirements.

Natural stone materials, particularly onyx, are of considerable interest because of their unique optical and aesthetic properties, which enable the integration of lighting systems into architectural components. The use of materials such as onyx, travertine, marble, and other natural stones in façades, flooring systems, and ceiling applications offers new opportunities for developing innovative architectural solutions capable of enhancing both the visual quality of spaces and user comfort. However, the successful integration of these materials into modern construction systems requires addressing several technical challenges, including the design of supporting structures, the uniform distribution of lighting, system reliability, and the adaptability of the proposed solutions to different operating conditions.

The existing literature demonstrates a sustained interest in the development of intelligent construction systems and the application of LED lighting technologies in architecture and interior design. Numerous studies have investigated the performance of natural stone materials, the energy efficiency of lighting systems, and their integration into contemporary architectural projects. Nevertheless, relatively few studies have proposed integrated construction solutions that combine natural stone materials, modular installation systems, and advanced lighting technologies within a unified framework suitable for both interior and exterior architectural applications.

Against this background, the research presented in this paper focuses on the development of innovative construction systems based on the use of natural stone materials, including onyx, travertine, marble, and other stones selected according to the aesthetic, mechanical, and optical requirements of each project, in combination with advanced lighting technologies and modular construction solutions. The study was carried out within a research and development project and aims to design and conceptually validate three innovative construction systems: a backlit façade system, an intelligent illuminated flooring system, and a modular illuminated ceiling system.

The proposed solutions are intended to improve the functional and aesthetic performance of architectural components through the integration of energy-efficient lighting systems, modular structural solutions, and construction concepts that facilitate installation, maintenance, and adaptation to various architectural configurations. At the same time, the research contributes to expanding the application of natural stone materials in architecture and interior design, providing the basis for the development of high-value, highly customizable construction products.

The paper is organized into five main sections. Following the introduction and literature review, the research methodology and the development stages of the proposed construction systems are presented. The subsequent sections describe the results obtained for each of the three innovative systems, analyzing their functional characteristics, advantages, and contributions to the development of modern construction solutions. Finally, the paper concludes with the main research findings and outlines directions for future research.

## 2. Literature Review

The use of natural stone in construction and architecture represents one of the oldest and most durable construction solutions, being widely recognized for its mechanical strength, durability, and aesthetic value. In recent years, research in construction materials has increasingly focused on the

development of innovative construction systems that capitalize on the functional properties of natural stone by integrating it into modern architectural solutions characterized by energy efficiency, design flexibility, and a high degree of customization [1], [2].

Among natural stones, onyx occupies a unique position due to its optical properties and its ability to transmit light. These characteristics make it particularly suitable for illuminated architectural applications, enabling distinctive visual effects and the development of architectural components with high aesthetic value. Recent studies have shown that the successful integration of onyx into architectural lighting systems requires dedicated structural solutions capable of ensuring mechanical strength, uniform light distribution, and operational safety [3], [4].

The rapid development of LED lighting technologies has created new opportunities for the use of natural stone materials in architecture and interior design. The literature indicates that modern LED lighting systems offer significant advantages in terms of energy efficiency, service life, design flexibility, and lighting control. When combined with natural stone materials, these technologies enable the development of backlit façades, illuminated flooring systems, and illuminated ceiling systems that integrate both aesthetic and functional characteristics [5], [6].

Another important research direction concerns the development of modular construction systems. The use of prefabricated components and modular supporting structures contributes to reducing installation time, improving construction quality, and facilitating maintenance and component replacement. For systems based on natural stone, modular solutions must ensure uniform load distribution, structural stability, and compatibility with integrated lighting systems [7], [8].

In the field of intelligent flooring systems, recent studies have highlighted the integration of sensors and automated control systems into construction assemblies to optimize energy consumption and enhance user experience. Occupancy-based lighting activation, continuous monitoring of operating parameters, and the use of low-voltage power supply are among the solutions that improve both energy efficiency and the operational safety of modern flooring systems [9], [10].

With regard to illuminated ceiling systems, the literature places particular emphasis on structural safety, seismic performance, and fire protection. The integration of natural stone panels into suspended ceiling systems requires specialized supporting structures, mechanical anchoring systems, and construction solutions that ensure both uniform light distribution and convenient access for maintenance operations [11], [12].

Beyond technical performance, current research also emphasizes the importance of sustainability and energy efficiency in the design of modern construction systems. The integration of LED lighting with natural stone materials, together with the use of optimized structural solutions, contributes to reducing energy consumption, extending system service life, and minimizing environmental impact, all of which are considered essential objectives in contemporary construction [13], [14].

A critical review of the literature reveals that most existing studies investigate the use of natural stone, lighting systems, modular structures, or solutions for façades and interior applications as separate research topics. However, relatively few studies propose an integrated approach in which natural stone materials, LED lighting technologies, and modular construction systems are developed together to create complete architectural solutions.

Addressing this research gap, the present study proposes the development and conceptual validation of three innovative construction systems for premium architectural applications: a three-dimensional backlit façade system, an intelligent illuminated flooring system, and a modular illuminated ceiling system. The proposed solutions are designed to capitalize on the aesthetic and functional properties of onyx, travertine, marble, and other natural stones through the integration of advanced lighting technologies and modular structural systems, thereby expanding the application potential of natural stone and supporting the development of high-value architectural products.

## 3. Materials and Methods

### 3.1. Research Framework

The research presented in this paper was conducted within a research and development (R&D) project carried out by Mesta Marmura și Travertin and aimed at the development of innovative construction systems based on the use of natural stone materials, including onyx, travertine, marble, and other natural stones, for illuminated architectural applications. The study focused on developing technical solutions capable of combining the aesthetic properties of natural stone with advanced lighting technologies, modular supporting structures, and construction solutions designed to meet current requirements for energy efficiency, safety, and design flexibility.

The research focused on the development of three distinct construction systems: an innovative three-dimensional backlit façade system, an intelligent illuminated flooring system, and a modular illuminated ceiling system. For each of these systems, the functional requirements, structural solutions, methods for integrating lighting systems, and the technical conditions required for implementation in architectural applications were systematically analyzed.

### 3.2. Research Methodology

The research methodology was structured into six sequential stages, summarized in Figure 1, to support the systematic development of the proposed construction systems and their technical and functional evaluation.

Figure 1. Research Methodology Workflow


Source: Authors' own elaboration

Figure 1 illustrates the sequence of the methodological stages adopted in this research. The proposed approach enabled the systematic development of the construction systems and their evaluation in terms of functionality, implementation feasibility, and the advantages they offer compared with conventional construction solutions.

**Stage 1 – Analysis of Architectural Requirements**

The first stage involved analyzing the functional and aesthetic requirements specific to premium architectural applications. Particular attention was given to the conditions required for integrating natural stone materials, including onyx, travertine, marble, and other natural stones, into backlit façades, illuminated flooring systems, and illuminated ceiling systems.

**Stage 2 – Analysis of Material Properties**

The second stage focused on analyzing the characteristics of the selected materials, with particular emphasis on the optical, mechanical, and functional properties of onyx, travertine, marble, and other natural stones, in order to establish the requirements for their application in illuminated construction systems.

**Stage 3 – Design of the Construction Systems**

Based on the identified requirements, conceptual designs were developed for the three proposed construction systems. This stage included the definition of the supporting structures, fixing mechanisms, and methods for integrating the various structural components.

**Stage 4 – Integration of the Lighting Systems**

This stage focused on the integration of LED lighting systems into the proposed construction systems, with particular attention to achieving uniform light distribution, high energy efficiency, and compatibility with the developed structural solutions.

**Stage 5 – Evaluation of the Technical Concepts**

The proposed construction systems were evaluated with respect to each research objective. The assessment considered functionality, structural safety, installation and maintenance requirements, as well as adaptability to different architectural applications.

**Stage 6 – Conceptual Validation**

The final stage consisted of a comparative analysis of the developed construction systems, highlighting their advantages over conventional approaches to the use of natural stone in construction and architectural applications.

Table 1. Research Stages

| Stage | Activity | Outcome |
|---|---|---|
| **Stage 1** | Analysis of architectural requirements | Definition of functional requirements |
| **Stage 2** | Analysis of material properties | Establishment of application requirements |
| **Stage 3** | Design of the construction systems | Conceptual designs for the three construction systems |
| **Stage 4** | Integration of LED lighting systems | Customized lighting solutions |
| **Stage 5** | Evaluation of the technical concepts | Assessment of technical performance |
| **Stage 6** | Conceptual validation | Validation of the proposed construction systems |

Source: Authors' own elaboration

The analysis of the research stages summarized in Table 1 demonstrates the systematic and progressive nature of the adopted methodology. Each stage contributes directly to achieving the research objectives and to the development of the proposed construction systems, ensuring a coherent and structured research process. The sequential progression through the stages of analysis, design, integration, and conceptual validation provided the technical foundation for the three innovative construction systems developed within this research. To assess the extent to which the research objectives were achieved and to qualitatively evaluate the proposed solutions, a set of technical and functional evaluation indicators was defined. These indicators reflect the principal performance requirements established throughout the research and development process.

### 3.3. Technical and Functional Evaluation Indicators

Each of the previously described research stages was aligned with the specific objectives of the project, namely the development of an innovative backlit façade system, an intelligent illuminated flooring system, and a modular illuminated ceiling system. To evaluate the extent to which the proposed construction systems satisfy the established functional and technical requirements, a set of technical and functional evaluation indicators was defined. These indicators enable the assessment of the construction systems with respect to modularity, energy efficiency, structural safety, ease of installation, maintenance accessibility, and architectural adaptability.

The evaluation indicators were selected to reflect the key characteristics considered during the design and development of the three construction systems and to provide a consistent qualitative assessment of the proposed solutions. They establish the framework for evaluating how effectively the project objectives have been translated into technical solutions capable of meeting current requirements for architectural applications based on onyx, travertine, marble, and other natural stone materials.

The evaluation indicators defined in this research are summarized in Table 2, where each indicator is associated with a relevant evaluation criterion for assessing the performance of the developed construction systems. Their selection was based on both the technical characteristics of the proposed systems and the functional and operational requirements specific to architectural applications employing onyx, travertine, marble, and other natural stone materials.

Table 2. Qualitative Evaluation Indicators

| **Evaluation Indicator** | **Evaluation Purpose** |
|---|---|
| Lighting Uniformity | Assessment of light distribution quality |
| Structural Safety | Assessment of the structural stability of the construction systems |
| Modularity | Assessment of the flexibility of the proposed solutions |
| Ease of Installation | Assessment of installation feasibility |
| Maintenance Accessibility | Assessment of system maintainability |
| Energy Efficiency | Assessment of energy consumption |
| Architectural Adaptability | Assessment of suitability for different architectural applications |

Source: Authors' own elaboration

The analysis of the evaluation indicators presented in Table 2 demonstrates that the assessment of the proposed construction systems extended beyond their structural characteristics to include aspects related to energy efficiency, modularity, maintenance accessibility, and architectural adaptability. The application of this set of evaluation indicators enabled a consistent qualitative assessment of the three construction systems developed in this research and provided the basis for the comparative analysis presented in the following section.

## 4. Proposed Construction Systems and Their Architectural Applications

### 4.1. Innovative Three-Dimensional Backlit Façade System

As part of the research, natural stone elements with various geometrical configurations—including triangular, hexagonal, and rectangular shapes—were analyzed and incorporated to enable the development of diverse architectural compositions. This geometric diversity enhances design flexibility while creating distinctive aesthetic and lighting effects tailored to specific architectural applications.

The natural stone elements can be processed using different cutting, grinding, and finishing techniques, resulting in a variety of edge profiles and surface angles that influence the reflection and diffusion of light. The selection of the finishing method is determined according to the architectural application and the desired visual effect.

The first outcome of the research is the development of an innovative three-dimensional backlit façade system based on the use of onyx, travertine, marble, and other natural stones, integrated into a modular structural framework. The proposed solution is designed to exploit the optical and aesthetic properties of these materials through the integration of an LED lighting system capable of providing uniform light distribution while enhancing the decorative appearance of the stone surfaces.

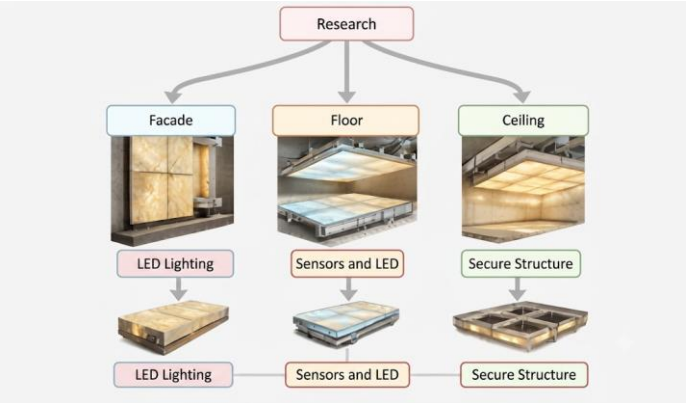
The development of the system was based on an analysis of the functional and structural requirements specific to façade applications. The objective was to create a solution combining mechanical performance, installation flexibility, and energy efficiency. The designed modular supporting structure enables the integration of natural stone panels into a structural system that facilitates installation, maintenance, and adaptation to a wide variety of architectural configurations.

The research also investigated methods for integrating the lighting system into the façade structure to ensure uniform light distribution while protecting the electrical components and maintaining convenient access for maintenance operations. Furthermore, the proposed solution aims to reduce energy consumption through the use of LED technology and an optimized structural configuration.

The implementation of the proposed system provides both functional and aesthetic advantages, contributing to the development of highly customizable and adaptable architectural façades. Compared with conventional façade solutions, the proposed system enables the integration of lighting without compromising the structural integrity of the construction elements while allowing the creation of visual effects tailored to the requirements of contemporary architectural projects.

The main outcome of this research is an integrated construction system in which the natural stone, the modular supporting structure, and the LED lighting technology operate as a unified system. The interaction among these components is essential for achieving the functional and aesthetic performance objectives established within the project. To provide an overview of this integrated approach, Figure 2 illustrates the conceptual structure of the innovative three-dimensional backlit façade system and its principal components.

Figure 2. Conceptual Structure of the Innovative Construction Systems Developed in This Research




Source: Authors' own elaboration

As illustrated in Figure 2, the proposed construction system consists of a modular supporting structure, natural stone panels, and an integrated LED lighting system. The adopted configuration ensures uniform light distribution, protects the technical components, and enables the system to be adapted to different dimensions and architectural configurations, thereby providing both high functional performance and superior aesthetic quality.

To highlight the main technical characteristics of the developed construction system, Table 3 summarizes the essential components and functionalities of the proposed solution. The information presented provides an overview of the features that distinguish the innovative façade system from conventional construction solutions and demonstrates the contribution of each component to the overall performance of the system.

Table 3. Summary of the Essential Components and Functionalities of the Proposed Construction System

| **Characteristic** | **Proposed Solution** |
|---|---|
| Primary Material | Onyx, travertine, marble, and other natural stones selected according to the specific application requirements |
| Supporting Structure | Modular |
| Lighting System | Integrated LED lighting |
| Installation | Modular and adaptable |
| Maintenance | Easy access to system components |
| Application Areas | Premium architectural façades |

Source: Authors' own elaboration

The information summarized in Table 3 highlights the main technical characteristics of the façade system developed in this research. The integration of a modular supporting structure, an energy-efficient LED lighting system, and natural stone materials enables the development of a construction system that meets current requirements for design flexibility, energy efficiency, and the aesthetic quality of architectural applications.

### 4.2. Intelligent Illuminated Flooring System

The second outcome of this research is the development of an intelligent illuminated flooring system composed of natural stone slabs, including onyx, travertine, marble, and other decorative stones, integrated into a modular supporting structure. The system accommodates elements with various geometrical configurations, such as hexagonal, triangular, and rectangular shapes, enabling the creation of highly customized architectural designs.

The LED lighting system is installed beneath the natural stone slabs, while the lighting layout is optimized to ensure uniform light distribution across the illuminated surface. The supporting structure is designed to withstand pedestrian traffic loads while providing convenient access to the electrical components for maintenance and servicing.

The proposed solution offers significant advantages in terms of energy efficiency, installation flexibility, and architectural versatility, making it suitable for integration into residential, commercial, hospitality, and other high-end interior environments.

### 4.3. Modular Illuminated Ceiling System

The third outcome of this research is the development of a modular illuminated ceiling system based on the use of natural stone panels, including onyx, travertine, marble, and other decorative stones, integrated into a suspended structure with an LED lighting system.

The system accommodates modules with various geometrical shapes and different stone finishes, allowing the ceiling design to be adapted to specific architectural concepts. The modular supporting structure facilitates installation, individual module replacement, and rapid access to the electrical installations for inspection and maintenance.

By combining the aesthetic properties of natural stone with LED lighting technology, the proposed system creates decorative ceilings characterized by uniform illumination, high energy efficiency, and a high degree of architectural customization.

## 5. Conclusions

This research demonstrates that the use of natural stone materials—including onyx, travertine, marble, and other decorative stones—in modular construction systems integrated with advanced lighting technologies represents a promising direction for the development of innovative architectural solutions.

The research findings demonstrate the feasibility of developing construction systems that combine the aesthetic properties of natural stone with contemporary requirements for energy efficiency, structural flexibility, and adaptability to a wide range of architectural projects.

Within the scope of this research, three innovative construction systems were developed: an innovative three-dimensional backlit façade system, an intelligent illuminated flooring system, and a modular illuminated ceiling system. Each system was designed to address specific functional requirements while sharing common design principles, namely the use of a modular structural framework and the integration of LED lighting technology. This approach expands the architectural applications of onyx, travertine, marble, and other natural stones and contributes to the development of high-value construction products with enhanced architectural performance.

The analysis of the proposed systems indicates that integrating natural stone materials with modern lighting technologies can significantly improve both the functional and aesthetic performance of architectural elements. Furthermore, the use of modular structural solutions facilitates installation and maintenance while providing greater flexibility for adapting the systems to different architectural configurations and project-specific requirements.

A key contribution of this research is the integrated design approach adopted for the three construction systems, which combines the properties of natural stone materials, modular construction technologies, and advanced lighting systems within a unified architectural concept. This approach contributes to expanding the applications of natural stone in construction and interior design while providing a foundation for the development of innovative solutions aligned with current architectural trends.

Although the present study is based on the development and conceptual validation of the proposed systems, the results indicate their considerable potential for implementation in architectural projects integrating decorative and functional lighting into construction elements. Experimental validation under real operating conditions and long-term performance assessment represent important directions for future research.

Future research may further extend these construction systems through the use of additional natural stone materials with suitable optical and aesthetic properties, the integration of intelligent lighting control systems, and the optimization of structural solutions with respect to energy efficiency, sustainability, and the digitalization of design and operation processes. These research directions may contribute to the development of a new generation of architectural products characterized by high technical performance, design flexibility, and superior aesthetic quality.

In conclusion, this research demonstrates that the integration of onyx, travertine, marble, and other natural stones into modular construction systems incorporating advanced lighting technologies represents a promising approach for the development of innovative architectural solutions. The proposed construction systems provide an integrated framework that combines natural materials, modular structural concepts, and energy-efficient lighting technologies, thereby expanding the application potential of natural stone in contemporary architecture and supporting the development of competitive, high-value products capable of meeting current demands for quality, customization, sustainability, and functional performance.

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