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# DEVELOPMENT OF A RESEARCH METHODOLOGY AND ARCHITECTURAL-URBAN APPLICATION OF INNOVATIVE CLADDING MATERIALS FOR THE FORMATION OF AN AESTHETICALLY EXPRESSIVE URBAN ENVIRONMENT

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**Abstract**

*This paper presents the results of a comprehensive research project focused on developing a testing methodology and exploring the practical application of innovative cladding materials—metal-ceramic panels ("QUANTUM CERAMIC") and aluminum honeycomb panels ("QUANTUM PARUS")—within an architectural and urban planning context. The study falls under the scientific specialty 2.1.13, "Urban Planning and Rural Settlement Design", and aims to assess the potential of these materials in addressing key contemporary urban planning challenges. These include creating an aesthetically expressive architectural character for urban spaces, enhancing visual harmony and environmental quality, providing safe and comfortable*

*living conditions, and reinforcing urban and regional identity. The proposed testing methodology involves a systematic evaluation of the materials' physical and mechanical properties, operational reliability, and resistance to climatic and chemical influences. It also assesses aesthetic characteristics, including colorimetric parameters and the visual perception of façades. Laboratory results confirm the high durability and resilience of the panels, as well as their compliance with relevant sanitary and hygienic regulations. The study further analyzes implemented urban projects in which these materials were applied to the cladding of transport, social, and cultural infrastructure facilities. The findings demonstrate that metal-ceramic and aluminum panels contribute to the harmonization of spatial environments, strengthen regional identity, and support the creation of visually comfortable and aesthetically expressive urban landscapes. The research substantiates the feasibility of incorporating these materials into comprehensive urban and rural development programs, aligning with modern standards of architectural design, operational reliability, and environmental sustainability.*

**Keywords:** Urban Planning, Architectural and Artistic Appearance, Visual Ecology, Testing Methodology, Innovative Materials, Metal-Ceramic Panels.

## I. Introduction

The strategic development of urban and rural settlements in the Russian Federation, in accordance with national projects and development strategies extending to 2040 [XI; XVIII], requires a comprehensive approach that integrates not only socio-economic and functional aspects but also aesthetic considerations. Of particular importance are the tasks of creating a visually expressive architectural character for cities, preserving historical, and establishing a comfortable and visually harmonious environment that responds to the challenges of contemporary development [III–IV]. [III–IV]. In this context, the development and implementation of new cladding materials that combine high-performance characteristics with broad design possibilities represent a significant scientific and practical challenge situated at the intersection of architecture, construction, and urban planning [II; XIV; XX–XXI]

The objects of the study were experimental samples of innovative materials: metal-ceramic panels ("QUANTUM CERAMIC"), consisting of DC04EK micro-alloyed steel with a three-layer glass-enamel coating, and aluminum panels ("QUANTUM PARUS") with an internal honeycomb core (see Fig. 1).

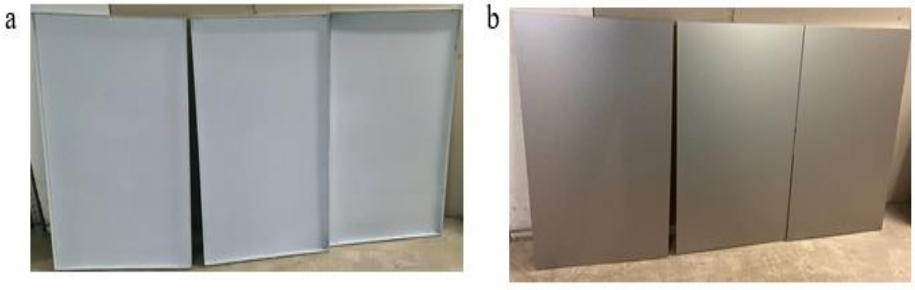

**Fig. 1.** Samples for testing: metal-ceramic panels (“QUANTUM CERAMIC”) and aluminum panels with an internal honeycomb core (“QUANTUM PARUS”)

Contemporary architecture and urban planning face the challenge of combining aesthetic expressiveness, functionality, and material durability. In the context of intensive urban infrastructure development, including transport facilities, railway stations, and public spaces, the importance of materials capable of maintaining their decorative properties over extended periods is increasing [VII]. One of the key factors influencing the perception of architectural objects is color design and its resistance to external influences, particularly ultraviolet radiation [XVII; XIX].

## II. Materials and methods

For this study, a comprehensive proprietary testing methodology for cladding systems based on metal-ceramic and aluminum honeycomb panels was developed and validated at the Department of Building Structures, Buildings, and Facilities of the Russian University of Transport. The methodology includes more than 15 types of tests: determination of geometric parameters and surface quality according to GOST 27180 [X] and ISO 10545-2 [XII]; flexural strength testing; measurement of water absorption; evaluation of frost resistance up to 400 cycles; and assessment of thermal stability over 100 cycles within the temperature range from −60°C to +80°C; hardness testing according to the Mohs scale; chemical resistance testing in acidic, alkaline, and hypochlorite environments; assessment of resistance to ultraviolet radiation and climatic influences over 80 cycles according to GOST 9.401 [IX]; and determination of flammability class [VIII].

The tests were carried out in laboratory facilities using calibrated equipment, including climatic chambers, spectrocolorimeters, universal testing machines, and other instruments. The physico-mechanical properties of the metal-ceramic panels demonstrated high flexural strength, with an average value of 35.3 MPa. Water absorption was found to be negligible, indicating high material density and durability.

Resistance to climatic influences was evaluated after 400 freeze–thaw cycles and 100 thermal cycles, with no defects observed in the form of cracks, chips, or delamination. UV resistance and durability under combined climatic factors were tested for up to 80 cycles, which engineering practice equates to approximately 10 years of service under temperate climatic conditions, and the tests confirmed the preservation of both decorative and protective properties of the coatings.

The panels exhibited high chemical resistance to solutions of citric acid, lactic acid, and alkaline media, with sensitivity observed only to concentrated hydrochloric acid (up to 18%). Fire safety tests allowed the materials to be classified into specific flammability groups, as confirmed by test protocols, meeting the requirements for use in transport infrastructure facilities.

Surface quality and geometry of the tiles were assessed by measuring maximum deviations of geometric parameters such as straightness, squareness, and warping. Deviations did not exceed 1.03%, corresponding to a high class of manufacturing precision.

The methodology for experimental studies and evaluations was based on a set of current regulatory, technical, and sanitary documents, ensuring the reliability and reproducibility of the results. In addition, the study utilized a proprietary testing methodology for metal-ceramic panels ("QUANTUM CERAMIC") developed at the Russian University of Transport (MIIT) [V], serving as an experimental framework that specifies exposure conditions and criteria for assessing adhesion, strength, and aesthetic characteristics. Furthermore, SanPiN 2.1.2.2645-10 "Hygienic Requirements for Living Conditions in Residential Buildings and Premises" [XVI], was employed to confirm the compliance of the materials with sanitary and hygienic standards and to ensure indoor environmental comfort.

The present study does not include a probabilistic reliability assessment (limit state functions, correlations between environmental factors such as temperature and UV radiation). All experimental conclusions are deterministic, following standard test methods. These methods are accepted for material certification and provide input values for design. The actual façade system incorporating the tested panels has been designed by licensed project organizations and has received a positive conclusion of the State Expert Appraisal [XV].

## III. Results

A modern airport is not merely a transportation hub but a regional landmark, serving as the "gateway" that shapes visitors' first and last impressions. The planned new passenger terminal of Kazan Airport, featuring metal-ceramic panels "QUANTUM CERAMIC" and aluminum panels with an internal honeycomb core "QUANTUM PARUS," serves as a striking example of how architecture can transcend utilitarian functions and become a powerful instrument of cultural expression and storytelling [I].

The central concept of the project is the harmonious integration of the rich historical heritage of Tatarstan with advanced technologies and the concise language of contemporary architecture (see Fig. 2).

**Fig. 2.** General view of the planned Kazan Airport terminal featuring metal-ceramic panels ("QUANTUM CERAMIC") and aluminum panels with an internal honeycomb core ("QUANTUM PARUS")

Kazan Airport represents a synthesis of recognizable elements, continuing motifs of historical architecture while complementing them with contemporary details: the structure of the Kremlin wall, the changing landscape, the foundations of the Tatar language and literature, a sense of warmth and grandeur, as well as the beauty and boundless depth of the soul of the people of the Republic of Tatarstan.

Building upon historical architectural motifs, designers and architects have skillfully highlighted key elements associated with Kazan and the Republic. The structure of the Kremlin wall is reflected in the terminal façades through rhythmic vertical divisions, visually referencing the regular spacing of the fortification towers and battlements of the Kazan Kremlin. This design approach creates a sense of monumentality and stability, evoking the impregnability and grandeur of the ancient citadel (see Fig. 3).

**Fig. 3.** The structure of the Kremlin wall is expressed through rhythmic vertical divisions, visually referencing the regular spacing of the fortification towers and battlements of the Kazan Kremlin, implemented using metal-ceramic panels ("QUANTUM CERAMIC") and aluminum panels with an internal honeycomb core ("QUANTUM PARUS")

The concept of a changing landscape is embodied through the undulating lines of interior spaces, the smooth curves of the ceiling, and dynamic lighting scenarios, which metaphorically convey the hilly terrain of the Republic and the vast expanses of the Volga and Kama rivers, creating a lively, breathing environment that avoids static monotony. A key element contributing to the contemporary and technological character of the terminal is the adaptive façade panels ("QUANTUM PARUS"). Their main advantage is adaptive colorimetry: depending on the time of day, weather conditions, and the angle of sunlight, the façade changes its hue. This creates a vibrant and dynamic appearance, shifting from silvery steel tones in the morning to warm golden shades at sunset. Such variability directly corresponds to the "changing landscape" concept [XIII], integrating the building into its natural surroundings (see Fig. 4).

**Fig. 4.** Adaptive color effects achieved through the use of metal-ceramic panels ("QUANTUM CERAMIC") and aluminum panels with an internal honeycomb core ("QUANTUM PARUS"). The façade changes its hue depending on the time of day, weather conditions, and the angle of sunlight

The foundation of the Tatar language and literature serves as the most subtle and profound level of ornamental design, seemingly integrated into decorative or wayfinding elements, inspired by traditional Tatar calligraphy — shamayily. This is not mere decoration but an encoded message linking the building to the cultural code of the people. The challenge of conveying intangible concepts was addressed through the interplay of materials and light. The interiors use natural and warm materials, such as wood and stone, creating a sense of hospitality and "warmth". The scale of the interior atriums and ceiling heights evokes a sense of "grandeur," while the interplay of light and shadow and complex volumes convey the "boundless depth of the soul" of the peoples of Tatarstan, their centuries-old wisdom, and serene strength (see Fig. 5).

**Fig. 5.** Ornamental motifs integrated into decorative and wayfinding elements, inspired by traditional Tatar calligraphy (shamayils)

The former Kazan Airport is an architectural monument of historical significance. In 2018, the terminal building at 47a Patrice Lumumba Street was designated as a cultural

heritage site of regional importance. Protected elements include the roof structure, façades and walls, the surrounding territory, as well as interior features such as original lighting fixtures, wall paintings, and column finishes.

The new Kazan Airport terminal is more than a building. It may be understood as an architectural composition created at the intersection of past and future. Rather than replicating historical forms, it subtly and intelligently translates the language of traditional culture into contemporary architectural forms and engineering solutions. This approach creates a unique identity, transforming a functional facility into a symbol of a forward-looking Republic of Tatarstan that remains deeply rooted in its heritage (see Fig. 6).

**Fig. 6.** Decorative solutions for interiors and wayfinding elements, inspired by traditional Tatar calligraphy (shamayils)

In this context, the concept of adaptive colorimetry involves the use of materials and coatings whose visual characteristics—color, texture, and gloss—exhibit inherent resistance to degradation. Innovative metal-ceramic panels ("QUANTUM CERAMIC"), combining high-strength steel with a multilayer glass-enamel coating, serve as a reference implementation of this approach. Their development addresses the challenges outlined in the Russian Federation's transport infrastructure development concepts, where durability, environmental sustainability, and visual identity are key priorities. The methodological foundation of this approach is colorimetry, supported by experimental testing [VI].

## IV. Conclusion

The developed comprehensive testing methodology enabled a thorough assessment of the operational characteristics of new architectural and construction elements. The results indicate that the metal-ceramic panels ("QUANTUM CERAMIC") and aluminum honeycomb panels ("QUANTUM PARUS") possess a range of superior physico-mechanical and performance properties: high strength and durability; exceptional resistance to atmospheric and thermal influences; chemical resistance to most reagents; compliance with fire safety requirements; and high surface quality and geometric precision.

These results provided the basis for a positive expert conclusion regarding the applicability of these materials for cladding both exterior and interior walls, including ventilated curtain façades, as well as for interior decorative finishes at prospective railway lines and stations, terminal complexes, stops, depots, and other transport infrastructure facilities in accordance with GOST and ISO standards.

The adaptive colorimetry implemented in "QUANTUM CERAMIC" and "QUANTUM PARUS" panels represents a synthesis of advanced materials science solutions and the requirements of contemporary architectural practice. The proven resistance of color and texture to ultraviolet radiation, chemical agents, and temperature fluctuations elevates these materials from ordinary finishing elements to strategic components capable of forming durable, visually stable, and aesthetically expressive environments. The deployment of such materials across transport infrastructure—from high-speed highways to urban stations—not only enhances operational reliability but also contributes to the creation of a new, high-quality visual identity for Russian cities.

**Conflict of Interest:**

The authors declare that there is no conflict of interest regarding this article.

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