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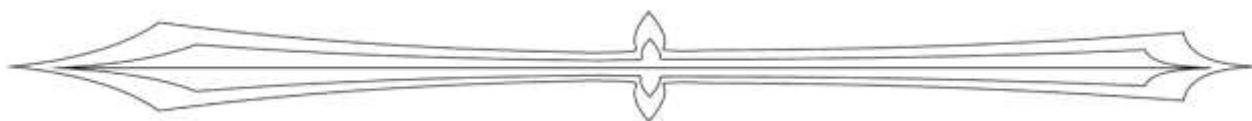
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PREFACE

Scientific society: employees of higher educational institutions and research institutes, including graduate students and students, as well as representatives of organizations and firms engaged in the field of knowledge-intensive business, welcome you to the 4th International Scientific and Practical Conference "Development and Design of Modern Materials and Products", organized based on the Engineering and Generative Design Department Dnipro University of Technology.

We are organizing a conference in the context of the Russian-Ukrainian war, which changed everything not only in Ukraine, in Europe, but also in the whole world.

We hope that such a conference is another opportunity to gather scientists from different directions and countries of the world, with the aim of preserving global scientific unity in such difficult conditions.

We are sure that the results of our joint work will be interesting and useful for all participants of the conference and will serve to solve modern problems of the world scientific community.

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IMPROVEMENT OF THE DOCUMENT MANAGEMENT SYSTEM AT AN AUTOMOTIVE ENTERPRISE TAKING INTO ACCOUNT MODERN REQUIREMENTS FOR OPERATIONAL AND MAINTENANCE MATERIALS

Abstract. The paper examines approaches to improving the document management system at an automotive enterprise under the conditions of digital transformation and increasing requirements for the accounting, control, and utilization of operational and maintenance materials. The importance of information integration for enhancing the efficiency of vehicle maintenance processes is substantiated.

Keywords: document management, automotive enterprise, digitalization, operational materials, maintenance, data management.

The effective organization of document management is one of the key conditions for the stable functioning of an automotive enterprise, especially under the growing complexity of technical processes, the expansion of the range of materials, and the need for precise accounting. The document management system, which covers all stages — from material ordering to their actual use during maintenance and repair — should not only ensure data preservation but also be fully integrated with the technological processes of the enterprise.

Given the modern trends in the development of the automotive industry, digitalization of document management has become an essential component. The transition to electronic data management systems ensures transparency of supply processes, reduces the risk of document duplication, and enables real-time monitoring of operational material inventories, such as lubricants, filters, suspension parts, fuel cells, and expendable electronic components. Such approaches contribute to greater accuracy in maintenance planning and reduction of material costs.

An important aspect of document management improvement is its connection to the enterprise's quality management system. Within the framework of ISO 9001:2015 and ISO/TS 16949:2016 standards [1, 2], special attention is given to the traceability of material usage, which makes it possible to form a complete operational history of vehicles and create a data foundation for analytical forecasting. The availability of a full digital service history improves staff accountability, simplifies control over compliance with technological requirements, and facilitates audits of production processes.



The improved document management system must also account for environmental and safety requirements concerning modern materials. In particular, the introduction of electronic Material Passports allows tracking of material composition, origin, degree of wear, and potential for reuse. This is especially relevant for hybrid and electric vehicles, where control over battery elements, next-generation lubricants, and composite body components plays a crucial role.

The further development of document management systems in automotive enterprises involves the implementation of artificial intelligence and data analytics algorithms capable of automatically classifying documents, predicting material needs, and detecting potential inconsistencies. Such solutions contribute to the creation of an adaptive management model that combines digital data processing with flexible regulation of production processes. Therefore, the improvement of the document management system at an automotive enterprise represents an essential component of the digital transformation of the transport sector. It ensures not only greater efficiency in managing material resources but also improves the quality of maintenance, vehicle reliability, and compliance with modern sustainability standards.

In the context of innovative development of automotive enterprises, the integration of document management systems with engineering software solutions such as CAD/CAM/CAE has become increasingly relevant. This integration enables the connection of technical documentation with design models, technological charts, and material characteristics of parts. Consequently, a closed information cycle is formed, encompassing both the production and operational phases of a vehicle. The informational interaction between subsystems can be represented in the form of a matrix data model:

$$D(t) = A \cdot X(t) + B \cdot U(t) \quad (1)$$

where $D(t)$ – is the data vector of documentation, $X(t)$ – e vector of product parameters, $U(t)$ – the vector of control actions within the document management system. Such models make it possible to forecast changes in technical information, ensuring consistency between design, maintenance, and material management processes. B – the matrices that define the interrelations between technical and administrative information flows within the enterprise's document management environment.

This model makes it possible to assess the dynamics of technical information updates and the consistency between design changes and corresponding records in the document database. To ensure calculation accuracy within the framework of integrated document management, it is advisable to apply a technical change coordination model based on the principle of minimizing discrepancies between current and archived data:

$$\min_{D_i} J = \sum_{i=1}^n (D_i^{\text{new}} - D_i^{\text{ref}})^2 \quad (2)$$

where D_i^{new} – updated data for the i -th document (technological chart, drawing, specification),

D_i^{ref} – reference data or the previous version of the document, J – the information consistency functional within the system.

Minimization of this functional is implemented using machine learning algorithms or analytical optimization methods, enabling the system to automatically determine the degree of data deviation and the necessity for record updates.

The interrelation between technological processes, material consumption, and the state of documentation can be represented through an integrated resource circulation model:

$$M(t) = M_0 - \int_0^t (C_r(\tau)) d\tau + \Delta M_{rec} \quad (3)$$

where $M(t)$ – the amount of material resources remaining at time t , M_0 – the initial stock of materials, $C_r(\tau)$ – material consumption for repair, $C_e(\tau)$ – material consumption for operational needs, ΔM_{rec} – the volume of returned or recovered materials.

The relationship between this model and the document management system lies in the fact that all parameters are integrated through electronic reports automatically generated based on data from CAD/CAM/CAE modules and the enterprise's ERP database.

The improved system enables the formation of a digital twin of document management, which can be mathematically described as:

$$S = \{(D_i, P_i, T_i, L_i) | i = 1, \dots, n\} \quad (4)$$

where D_i – the document, P_i – the product parameters, T_i – the creation and update timestamps, L_i – the logical connections between documents.

Thus, the model ensures traceability of all changes, creating an integrated knowledge management system in automotive manufacturing.

Conclusions. The integration of the document management system with engineering software solutions such as CAD/CAM/CAE establishes a new level of production information organization, in which technical, material science, and administrative data operate within a unified digital environment. The use of mathematical models in this process allows not only to describe but also to predict the behavior of the document management system in real time, ensuring adaptability and controllability of information flows.

The matrix model of data exchange provides a structured interaction between design parameters and management decisions, facilitating synchronization of technological processes and reducing the likelihood of errors. The model of technical change coordination makes it possible to assess the accuracy of technical information updates, while the discrepancy minimization functional increases the reliability of data within the system.

The integrated model of material resource circulation connects technical documentation with the processes of planning and monitoring the consumption of operational and maintenance materials. This enables the formation of adaptive reports that are automatically updated based on enterprise electronic databases, ensuring continuity of the information cycle from product development to disposal.

Therefore, the application of mathematical models in digital document management systems ensures the creation of an *intelligent data management architecture*, which forms the foundation for the transition of automotive enterprises to Industry 4.0 standards. Such a system enhances management efficiency, reduces time spent on document processing, minimizes information loss risks, and ensures technological flexibility in vehicle maintenance and repair processes.

In the long term, the implementation of digital twins of document management systems and artificial intelligence analytical algorithms will create a new format of technical management, in which documents become an active element of the production system rather than merely a data carrier. This will ensure complete traceability of a product's technical history, improve the quality of managerial decisions, and become the basis for the sustainable development of automotive enterprises in the digital era.

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MODERN STRUCTURAL AND BIOCOMPATIBLE MATERIALS FOR ENDOPROSTHESIS OF THE MUSCULOSKOLE SYSTEM AND THEIR PERFORMANCE CHARACTERISTICS

Abstract. The key requirements (strength, wear resistance, biocompatibility) for materials for endoprostheses of the musculoskeletal system are analyzed. The properties and applications of titanium alloy Ti₆Al₄V (osteointegration), Co-Cr-Mo alloys (high hardness, wear resistance), ceramics (wear minimization) and UHMWPE (inserts) are considered. The importance of these materials for the long-term success of implantation is emphasized.

Keywords: Endoprosthesis, biomaterials, Ti₆Al₄V, cobalt-chromium alloy, ceramics, ultra-high molecular weight polyethylene, osteointegration, biocompatibility.

Modern structural materials used in endoprosthetics of the musculoskeletal system must simultaneously meet the requirements of mechanical strength, wear resistance, corrosion resistance and biocompatibility. This is due to the fact that implants operate under conditions of constant load, contact with biological fluids and dynamic changes that occur during movement. The long service life of an endoprosthesis is determined not only by the design, but also by the choice of the optimal material for each component, which ensures the stability of the endoprosthesis, the absence of toxic corrosion products, minimal formation of wear particles and acceptable load transfer to bone tissue [1].

One of the most widely used materials is the titanium alloy Ti₆Al₄V, which combines low density (about 4.4 g/cm³) with high strength (up to 900 MPa), making it ideal for loaded components of hip and shoulder endoprostheses [1].

Due to its low modulus of elasticity (approximately 110 GPa), which is closer to that of bone, titanium reduces the phenomenon of “alternating load” — the transfer of load from bone to implant, which can cause bone tissue atrophy. The surface of titanium independently forms an oxide layer of TiO₂, which provides stable corrosion resistance in the physiological environment, preventing the release of metal ions. The biocompatibility of titanium allows for successful osseointegration — direct structural contact of the bone with the implant surface, which ensures its reliable fixation without the

use of cement. This is of particular importance in young patients and in revision prosthetics, where maximum stability and minimal tissue reaction are required [1].

For parts subject to intense friction, cobalt-chromium alloys (Co-Cr-Mo) are used, which are characterized by high hardness, low wear coefficient and ability to withstand significant cyclic loads without plastic deformation. Their mechanical strength can reach 1000–1200 MPa, which is important for the heads of hip and knee joint endoprostheses. In addition, Co-Cr alloys demonstrate stable corrosion behavior in chloride-rich environments, which makes them resistant to pitting and crevice corrosion. The biocompatibility of these alloys has been confirmed by many years of clinical experience, although there is a risk of increased release of cobalt ions in case of improper polishing, which requires quality control of production [2].

Ceramic materials have become widely used - aluminum (Al_2O_3) and zirconium (ZrO_2) ceramics. Their key advantages are extremely high abrasion resistance (tens of times higher than metal), chemical inertness and complete biocompatibility. Ceramic heads ensure minimal formation of wear particles, which is critical for increasing the service life of the prosthesis and preventing the development of osteolysis. Due to the uniform, smooth and superhard surface, the friction coefficient in the “ceramic-ceramic” pair is one of the lowest among all available materials. This reduces the likelihood of overheating and local tissue destruction, ensuring stable and predictable joint operation [2].

Ultra-high molecular weight polyethylene (UHMWPE) is used to make acetabular cup liners and tibial platforms in knee prostheses. Its properties include high impact strength, fatigue resistance, and low coefficient of friction. In modern orthopedics, cross-linked polyethylene (UHMWPE) is most often used, which demonstrates a significantly lower level of wear due to its modified molecular structure. This significantly reduces the number of microparticles that enter the surrounding tissues and can cause aseptic loosening of the implant. The material is biocompatible and does not cause immune reactions, and the long-term stability of the polymer ensures reliable operation of the implant for many years [2].

In addition to the basic materials, bioactive coatings (e.g. hydroxyapatite) are actively used to stimulate implant adhesion and improve bone contact. They form a chemical bond with the tissue, which further increases stability. Recent developments include gradient structures and porous 3D-printed titanium components that mimic the microstructure of bone and enhance bone regeneration by allowing cells and blood vessels to enter the pores [3].

Table 1 - Properties of materials for endoprosthetics

Material	Mechanical strength	Durability	Corrosion resistance	Biocompatibility	Features
Titanium alloy Ti ₆ Al ₄ V	Up to 900 MPa	High	Stable, oxide layer	High	Reduces alternating load, ensures osseointegration
Cobalt-chromium alloy (Co-Cr-Mo)	1000-1200 MPa	Low wear rate	Resistance to pitting and crevice corrosion	High	High hardness, resistance to cyclic loads
Ceramics (Al ₂ O ₃ , ZrO ₂)	High	Very high	Chemical inertness	Complete	Minimal formation of wear particles, low coefficient of friction
Ultra-high molecular weight polyethylene (UHMWPE)	High	Low wear rate	Fatigue damage resistance	High	Cross-linked polyethylene has a lower level of wear
Bioactive coatings (hydroxyapatite)	Not specified	Not defined	Not defined	High	Stimulates implant adhesion, improves contact with bone

Thus, modern materials for endoprosthesis combine high mechanical durability, chemical stability and biocompatibility, which ensures safe and effective operation of implants for a long time. Titanium alloys provide an optimal ratio of strength and biological inertness, cobalt-chromium alloys guarantee wear resistance under high loads, ceramics minimize particulate wear, and polyethylene provides effective shock absorption and stable interaction between the components of the

endoprosthesis. The combination of these properties makes such materials the basis of modern orthopedic implantology [3].

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STUDY OF THE ELECTRICAL CONDUCTIVITY OF NANOSTRUCTURED BIOMATERIALS

Abstract. Electrospinning is considered for leading nanostructured biomaterials in biomedicine, sensors, neurointerfaces, tissue engineering, and drug delivery. Direct spinning uses doping to improve solubility, mechanical properties, and conductivity through chain orientation. Coaxial creates stable, biocompatible core-shell hybrids; Stencil methods with inorganic substrates yield structures with large surface area and low impedance for biosensors/neural interfaces. The factors analyzed enable the creation of customized solutions that overcome limitations for clinical electronic applications.

Keywords: electrospinning, conductive polymers, nanostructured biomaterials.

In recent decades, researchers have focused considerable attention on the development of nanostructured biomaterials with electrical conductivity. Such materials are used in biomedicine, sensor technology, neurointerfaces, tissue engineering, and controlled drug delivery systems. Among modern synthesis technologies, electrospinning holds a prominent position, as it allows the production of nanofibers with a high degree of molecular chain orientation and tunable physicochemical properties.

The purpose of this study is to analyze modern approaches to obtaining electrically conductive nanostructured biomaterials by electrospinning, as well as to determine the factors that affect the electrical conductivity of the obtained fibers and composite structures [1].

Electrospinning is based on the ejection of a jet of polymer solution or melt under the action of a high-voltage electrostatic field, resulting in the formation of nanofibers with diameters ranging from tens to hundreds of nanometers. Due to its simplicity, low cost, and versatility, the method is widely used to create electrically conductive polymer fibers, such as polyaniline (PANI), polypyrrole (PPY), and poly(3-hexylthiophene) (P3HT). However, the low solubility and mechanical brittleness of these polymers significantly limit the efficiency of direct electrospinning, requiring the introduction of new technological approaches and modifications [2].

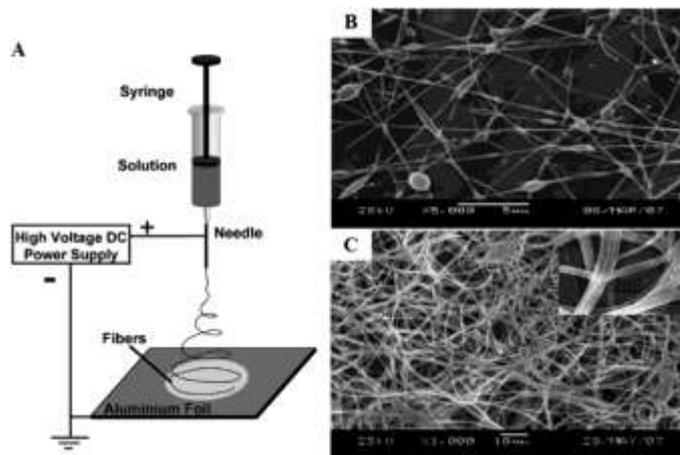


Figure 1. A – Schematic diagram of the direct electrospinning method. B, C – SEM images of fibers formed with a polyaniline (PANI) concentration: B) 10.6% C) 14.0%. Using concentrated sulfuric acid as a doping additive [3].

Direct electrospinning of conductive polymers is limited due to their rigid structure, low molecular weight, and limited solubility in organic solvents. To improve properties, chemical doping strategies are used the introduction of acidic additives that increase solubility and electrical conductivity. Experiments have shown that PPY nanofibers obtained by this method demonstrate conductivity that exceeds that of PPY films by two orders of magnitude, which is associated with the orientation of molecular chains during the elongation process [2].

Coaxial electrospinning, in turn, allows the production of core-shell fibers using coaxial nozzles through which two polymer solutions are fed. This design ensures control over the distribution of materials and allows the creation of composites with improved mechanical stability and electrical conductivity. The use of PANI or PPY in combination with polyvinylpyrrolidone, polyurethane, and polyvinylidene fluoride increases the mobility of charge carriers and improves the flexibility of the material [4].

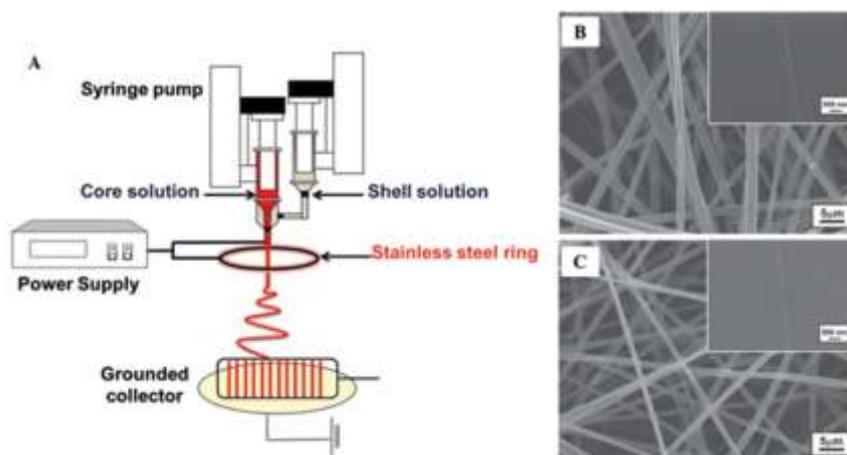


Figure 2. A – Schematic diagram of the coaxial electrospinning method.

B, C – Images of P3HT-PMMA fibers with a core and shell obtained using FE-SEM:

B – without a secondary electric field and C – with a secondary electric field [5]

Coaxial P3HT–PMMA fibers showed an increase in charge mobility by almost three orders of magnitude compared to samples obtained by the conventional method, confirming the effectiveness of this approach for improving the conductivity and structural uniformity of electrospun fibers.

Co-electrospinning with other polymers is an effective way to improve the processability and mechanical stability of fibers. Mixing polymers with soluble polymers, such as polyethylene oxide or sericin, allows obtaining hybrid composites with improved mechanical properties while maintaining electrical conductivity. For example, co-electrospinning PANI 3 camphorsulfonic acid and polyethylene oxide allowed to achieve a conductivity of 1.73 S/cm, which is two orders of magnitude higher than in similar structures without secondary doping. Such fibers have high flexibility and biocompatibility, which makes them promising for the creation of electrically conductive scaffolds in regenerative medicine and tissue engineering [6].

Template methods for synthesizing nanostructured conductive materials are based on the use of electrospun fibers as a matrix for further polymerization, which ensures the formation of nanotubes, nanochannels, and core-shell structures. Such methods, in particular solution polymerization, in situ electrochemical polymerization, and vapor phase deposition, allow obtaining materials with a large specific surface area, controlled morphology, and high electrochemical characteristics. During the electrochemical deposition of polymers such as PEDOT and PPY, nanostructures are formed on the surface of electrospun fibers, which significantly reduce impedance and increase the surface capacitance of electrodes. This increases the efficiency of electrical signal transmission in a biological environment, making such materials promising for the creation of highly sensitive microelectrodes and neural interfaces [7].

The use of inorganic templates such as TiO_2 , Mn_2O_3 , or V_2O_5 allows for further expansion of the functional capabilities of electrically conductive structures.

Such materials combine conductivity with photocatalytic activity, chemical stability, and biocompatibility, making them suitable for the creation of biosensors and flexible electronic devices. In particular, PANI and PEDOT nanotubes obtained on inorganic substrates by vapor phase deposition demonstrate stable electrical conductivity.

CONCLUSION

Electrospinning excels in fabricating conductive nanostructured biomaterials for biomedicine, sensors, neurointerfaces, tissue engineering, and drug delivery. Doping enhances direct spinning of PANI, PPY, P3HT, improving solubility, mechanics, and conductivity via chain orientation.

Coaxial/co-electrospinning creates stable, biocompatible core-shell hybrids (e.g., with PMMA, PEO, sericin) for regenerative scaffolds. Template methods using inorganic substrates (TiO₂, Mn₂O₃, V₂O₅) produce high-surface structures with low impedance for biosensors and neural interfaces.

These approaches address polymer drawbacks, enabling customization. Future focus is scaling, in vivo compatibility, and multifunctionality for clinical electronic progress.

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AUTOCLAVE MATERIAL BASED ON IRON ORE BENEFIT TAILS

Abstract. The granulometric compositions of tailings from the enrichment of iron ores of the Southern and Ingulets mining and processing plants according to the stages of their wet magnetic separation have been determined. The feasibility of using waste iron-bearing quartzite's of the first stage of enrichment as a silica component of aerated concrete mixtures has been proven. In terms of physical and mechanical properties, the studied autoclaved aerated concrete meets the requirements of state standards of Ukraine.

Keywords: composite material, silica component, waste from the enrichment of ferruginous quartzites

Solving the problem of industrial waste utilization in the production of modified composite materials is of great scientific and practical importance, which will allow us to obtain new information about their structure and properties, expand the raw material base, and contribute to the ecological improvement of the environment. Secondary products of iron ore production include large-tonnage waste from the enrichment of ferruginous quartzites (tailings) of mining and processing plants (MPP).

At all mining and processing plants, the methods of enrichment of iron ores are fundamentally the same [1]. Using magnetic separation, the rock is removed from the sequentially crushed iron ore, leaving the maximum percentage of iron. When enriching ferruginous quartzites by wet magnetic separation, a large amount of finely dispersed waste is released.

The following materials were used to prepare the aerated concrete mixture: as a siliceous component – waste from the enrichment of ferruginous quartzites (tailings), Portland cement grade M500, calcium lump quicklime, gas generator – aluminum powder PAP-1 (pigment), surfactant – sulfanol; water met the requirements of DSTU B V.2.7-273:2011.

The temperature of the aerated concrete mixture on a cement-lime binder at the time of unloading into the mold was 40°C. Cube samples with an edge of 0.07 m were formed, which, when the required plastic strength of the raw material was achieved, were subjected to autoclave treatment according to the appropriate regime.

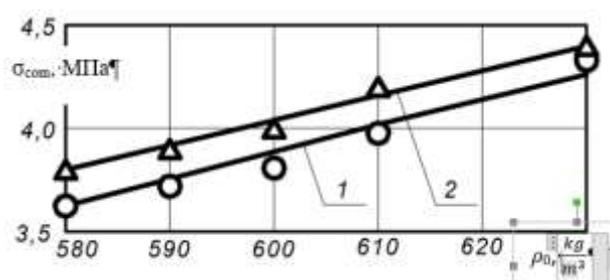
It was established that the current enrichment waste at the Southern Mining and Processing Plant is represented (in percentage by mass) by 0.2-15.4% by a fraction with a size of >0.25 mm; by 0.2-18.3% by a fraction of 0.25-0.16 mm; by 0.4-19.0% by a fraction of 0.16-0.071 mm; by 51.33% by a size of <0.071 mm; by 45.0-98.8% by a size of <0.05 mm.

Tailings at the Ingulets Mining and Processing Plant have the following granulometric composition (in percentages by mass): particles with a size of >0.25 mm – 0.1-5.2%; particles of the 0.25-0.16 mm fraction – 0.1-11.0%; particles of the 0.16-0.071 mm fraction – 0.4-20.2%; particles with a size of <0.071 mm – 61.7-98.6%; particles with a size of <0.05 mm – 53.6-95.6%.

As can be seen from the test results, the waste from the enrichment of ferruginous quartzites at the Southern Mining and Processing Plant is larger than that at the Ingulets Mining and Processing Plant. Starting from the 0.16-0.071 mm fraction, the number of particles of which is the same at both plants (0.4-19.0% and 0.4-20.2%, respectively), the share of grains with a size of <0.071 mm and <0.05 mm at the Ingulets Mining and Processing Plant is 10% higher. The distribution of the material by fractions is determined by the mineral composition, grain size, and nature of the intergrowths of magnetite with other non-metallic minerals in the source ferruginous quartzites, as well as the degree of grinding of mineral raw materials at enrichment plants.

The calculated consumption of components per 1 m³ of aerated concrete mix on tailings at both mining and processing plants is almost the same. Since the size of the waste from the Ingulets Mining and Processing Plant is smaller than that from the Southern Mining and Processing Plant (the number of particles <0.071 mm is 61.7-98.6% versus 51.3-99.4%, respectively), more new formations (hydro-silicates $2\text{CaO}\cdot\text{SiO}_2\cdot n\text{H}_2\text{O}$, hydroaluminates $3\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot 6\text{H}_2\text{O}$, hydroaluminoferrites $4\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot\text{Fe}_2\text{O}_3\cdot 4\cdot n\text{H}_2\text{O}$ calcium etc.) with a larger amount of chemically involved water are formed on these wastes. Therefore, the amount of unbound water in the concrete made with Ingulets GOK tailings was lower than in that made with Southern MPP tailings. Therefore, the moisture content of the aerated concrete based on tailings of the Southern MPP is higher than that of the concrete based on tailings of the Ingulets MPP (on average by 4.4%) [2].

The average density of the studied autoclaved aerated concretes using tailings from the enrichment of iron ores in Kryvbas ranged from 580 kg/m³ to 630 kg/m³ (figure).



1 – Southern Mining and Processing Plant; 2 – Ingulets Mining and Processing Plant

Figure. Dependence of the compressive strength of autoclaved aerated concrete σ_{com} based on iron ore enrichment tailings on its average density ρ_0

According to DSTU B V.2.7-45:2010, such aerated concrete belongs to the D600 grade by average density. The compressive strength of these concretes varied from 3.65 MPa to 4.40 MPa (figure). Therefore, such aerated concrete belongs to the C2.5; C3.5 class by compressive strength and belongs to the heat-insulating and structural type.

The physical and mechanical properties of concrete largely depend on the strength of the bond between the cement stone and the surface of the aggregates and fillers, as well as on the size of their particles. The real surface of a solid is always bifunctional, since it is a collection of Brønsted and Lewis centers of both basic and acidic types.

According to the Brønsted definition, an acid is a substance that is a proton donor. A substance that is a proton acceptor is called a base (i.e., the main characteristic of an acid is the presence of a proton in its molecule). Lewis defined an acid as a substance that can accept a lone pair of electrons from another molecule to form a stable electron shell. A base, according to Lewis, is a substance that, having a lone pair of electrons, can become a donor of electrons to form a stable electron configuration of another atom. Thus, Lewis acids and bases may not contain protons, that is, be aprotic.

Thus, Brønsted and Lewis bases are the same particles and molecules. However, Brønsted basicity is the ability to attach only a proton, while Lewis basicity is a broader concept and means the ability to interact with any particle that has a low-lying unoccupied orbital.

The ions on the silica surface are both acidic due to the presence of vacant orbitals (silicon) and basic, having donor properties (oxygen) of Lewis centers. When the silica surface is hydroxylated, proton-donating and proton-accepting Brønsted centers appear on it.

The strength of acids and bases is quantitatively estimated by the constant of protolytic (proton transfer reaction from acid to base) equilibrium (pK_a), which is determined experimentally and is the negative decimal logarithm of the product of the molar concentrations of water ions $[H^+] \cdot [OH^-]$ (p is the initial letter of the German word *potenz* – an indicator of mathematical power; index a – acid, acid).

The strength of concrete increases with increasing content of Brønsted acid centers ($pK_a = 0-7$) and Lewis basic centers ($pK_a = -4,4-7$). With increasing content of pK_a from -4.4 to 7, the mechanical properties of composites improve and the degree of cement hydration increases. Fillers with centers of sufficient intensity in the regions with $pK_a = 4.4$ to 7 and above 13 are capable of catalytically activating the hydration of the binder. The acceptor properties of the surface of solid phases with $pK_a > 13$ contribute to increasing the plastic strength of cement (and, therefore, concrete). As the aggregate dispersion increases, the content of Lewis basic and total centers increases. This explains the increase

in the strength of composites with a decrease in the particle size of the material, and also predicts an increase in the degree of hydration of the binder.

The tailings from the enrichment of ferruginous quartzites at the Inguletsk Mining and Processing Plant are finer than those at the Southern Mining and Processing Plant. Therefore, the strength of autoclaved aerated concrete using tailings from the Inguletsk Mining and Processing Plant is higher than that using tailings from the Southern Mining and Processing Plant (figure).

The strength of aerated concrete is also affected by the solubility of silica, which is naturally low. In the technology of autoclaved materials, the size of the silica component is of great importance – the smaller it is (the higher its specific surface area), the more silica passes into the solution for combination with lime, and the more neoplasms are created during autoclaving. Chalcedony-like, re-actively metamorphosed, and partly dynamo-metamorphic quartz generation of waste from wet magnetic separation of ferruginous quartzites intensively binds calcium hydroxide into finely crystalline insoluble calcium hydrosilicates, which helps reduce the number of defects, reduce crystallization pressure, and optimize the material structure.

Products made on the basis of waste from the enrichment of ferruginous quartzites of the Southern and Ingulets mining and processing plants meet the requirements of DSTU B V.2.7-45:2010 "Aerated concrete. General technical conditions" and DSTU 9184:2022 "Wall products made of aerated concrete. Technical conditions".

The environmental efficiency of recycling tailings from iron ore enrichment contributes to the elimination of tailings and frees up useful land areas (thereby reducing the burden on the natural environment in iron ore regions). The advantages of using tailings are: the possibility of producing low-cost cellular concrete based on them.

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USING RENEWABLE AND RECYCLED MATERIALS IN TRANSFORMABLE FURNITURE DESIGN

Abstract: The transforming bench "Compact Eco" was studied, which allows for efficient use of space. The transformation mechanism and materials were analyzed. The choice of pressed bamboo and recycled aluminum/steel was justified with an emphasis on sustainability, durability and minimization of the carbon footprint, and ecological alternatives (FSC, WPC, HDPE) were also evaluated.

Keywords: Transformer "Compact Eco", pressed bamboo, circular economy, recycling materials, transformation mechanism, sustainable design.

In modern furniture design, where space constraints and environmental responsibility have become key criteria, there is a need to create solutions that combine intelligent functionality, sustainability and aesthetic perfection. The concept of the transforming bench "Compact Eco" reflects this philosophy, offering a minimalist design with a unique transformation function and a responsible approach to the selection of raw materials. The design of the transforming bench is a conscious departure from bulky forms, characterized by clean, rounded lines that visually lighten the structure and increase safety. When folded, it functions as a stylish console, without overloading the space, and when transformed, it easily doubles or triples the usable seating area thanks to the reliable transformation mechanism, which is built on a system of hidden guides, which ensures smooth, quiet and wear-resistant operation.

When choosing materials for the transforming bench, their environmental friendliness and durability were important, while maintaining high strength and attractive design.

For the manufacture of the main body, which includes support and seating elements, pressed bamboo was chosen as the priority material. This choice is justified by a combination of high performance characteristics and environmental sustainability. Bamboo is classified as a rapidly renewable resource with a short growth cycle of only 3–5 years, which significantly reduces the load

on forests. Pressed bamboo has high hardness (Brinell index reaches 4.0), which guarantees the necessary mechanical stability and resistance to deformation, which is critically important for load-bearing structures. In addition, its natural moisture resistance allows you to expand the scope of application of the module: the bench can be used not only indoors, but also outdoors (on terraces or balconies). However, the use of pressed bamboo has certain disadvantages, including a limited palette of natural colors and textures compared to the variety of traditional wood species. Also, the quality of the final material depends on the pressing technology and the type of glue used, which requires strict control of the content of volatile organic compounds (VOCs) in the binding components to ensure environmental safety and minimize the risks of releasing harmful substances.

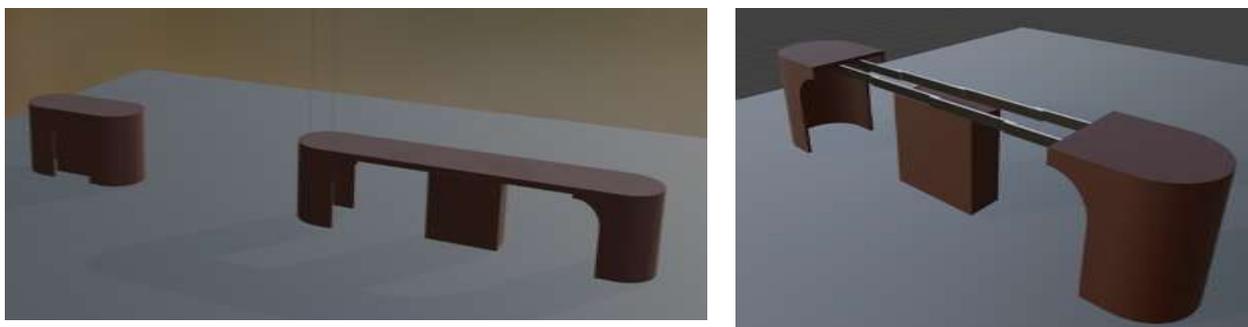


Figure 1 - General view of the transforming bench "Compact Eco"

To ensure reliable operation and durability of the composite mechanism (guides) of the Compact Eco bench-transformer, it is proposed to use recycled aluminum or steel, which will have significant environmental benefits, since the recycling process, especially aluminum, allows minimizing the impact on the environment by reducing energy consumption by up to 95% compared to the production of primary metal. Both materials provide the necessary rigidity, high strength and durability, which is important for elements that are constantly exposed to dynamic loads during the transformation process. Additionally, stainless steel is used for connecting elements (bolts and screws), which guarantees structural reliability and corrosion resistance, which is important when operating the bench in the outdoor environment. However, there are also certain disadvantages: recycled aluminum has an average cost that is higher than some primary metals, and the use of steel, despite its strength, increases the total weight of the structure, reducing its portability.

Regarding the durability and environmental safety of external surfaces, natural oils and hard waxes that are safe for the user and the environment are used as a protective coating, as they do not contain volatile organic compounds (VOCs). The coating penetrates deeply into the bamboo structure, effectively protecting it from UV radiation and moisture, thereby significantly extending the product's

service life and maintaining its high environmental profile. The disadvantages of natural oils and waxes include the need for periodic renewal (regular maintenance), which requires additional efforts from the user to maintain optimal protective properties.

To ensure production flexibility and meet various market demands for environmental responsibility and performance, we will consider a number of alternative materials with official certification and high technical indicators, along with the main material (bamboo).

One promising option is thermomodified wood (in particular, ash or maple). The advantages of this material are that thermal treatment significantly increases its resistance to moisture, rot and pests without the need for chemical impregnations. Thermowood demonstrates high dimensional stability and durability. The use of local wood species also contributes to reducing the carbon footprint during transportation. However, the thermomodification process itself is energy-intensive, and the material after treatment can become more fragile, requiring caution during mechanical processing.

Another group of materials is certified wood (FSC), as FSC certification guarantees responsible forest management and the selection of wood exclusively from controlled forests, confirming the environmental profile of the product. Certified wood provides traditional strength and high aesthetic appeal, but these indicators depend significantly on the specific species chosen, and for outdoor use, careful additional protection from external factors is often required.

A good ecological alternative is agglomerated cork composite (from cork oak), as cork oak is a completely renewable resource. The material is lightweight, which increases the mobility of the bench, and has a high resistance to moisture and mold. At the same time, lower mechanical strength and hardness compared to bamboo or traditional wood limits its use for highly loaded load-bearing elements. The material also has a higher cost compared to bulk materials.

In addition to wood-based materials, recycled polymers play an important role. Recycled plastic (HDPE), which has a service life of up to 50 years, high resistance to moisture, UV radiation, salt and insects, does not require painting, is one of the most promising environmentally friendly materials for outdoor furniture. The disadvantage is the lack of natural wood aesthetics and lower rigidity compared to wood. By using HDPE, you can get rid of a lot of plastic waste from landfills and ensure full reuse of the material.

Recycled wood-polymer composite (WPC) combines the aesthetics of shredded wood (using wood processing waste) with the durability of recycled plastic, requiring minimal maintenance, making this material ideal for outdoor structures and surfaces. At the same time, WPC is not completely environmentally friendly due to the presence of polymers, and its difficulty in recycling is higher compared to pure recycled plastic.



Figure 2 – Options for using the “Compact Eco” transforming bench

Thus, the concept of the transforming bench "Compact Eco" demonstrates the combination of minimalist, adaptive design with engineering solutions and a deeply thought-out choice of materials, focused on the circular economy and minimizing the carbon footprint. The use of bamboo and recycled metals confirms that durability and high aesthetics can be achieved without compromising a sustainable future.

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DEVELOPMENT AND RESEARCH OF BUDGET REFRACTORY COMPOSITE MATERIALS BASED ON TITANATE-SILICATE COMPOUNDS

Abstract. The article presents the planning and initial stage of experimental research to create a new recipe for lightweight refractory material. The basis is budget raw materials: quicklime (CaO), quartz flour (SiO₂), titanium dioxide (TiO₂) and perlite. The first stage is set to optimize the chemical composition of the binding matrix and determine the optimal firing temperature to achieve maximum mechanical strength and fire resistance. Hardening at the initial stage is provided by a combination of technological binder (gypsum) and carbonization of calcium hydroxide.

Keywords: calcium oxide, calcium hydroxide, titanium dioxide, quartz flour, perlite, silicate, titanate, perovskite.

The development of energy-efficient technologies in industry is inextricably linked to the development of new, cost-effective refractory materials for thermal insulation of furnaces and high-temperature units. Traditional aluminosilicate and magnesia refractories are often expensive to produce. The proposed composition is a lightweight refractory material based on a combination of calcium, silicate and titanate phases, which can be formed from relatively cheap and accessible raw materials:

Quicklime (CaO): Used as a source of calcium (Ca²⁺) and is the main binding component. Upon reacting with water, it forms calcium hydroxide Ca(OH)₂, which undergoes carbonization at room temperature ($\text{Ca(OH)}_2 + \text{CO}_2 \rightarrow \text{CaCO}_3 + \text{H}_2\text{O}$), providing initial strength. [1] During high-temperature firing, CaCO₃ decomposes, and the resulting active CaO reacts with other components.

Titanium dioxide (TiO₂) is a high-temperature additive that is critical for the formation of calcium titanates (CaTiO₃) and titanosilicates (CaTiSiO₅). These phases are characterized by high melting points and chemical stability, which contributes to the increased refractoriness of the final material. [2]

Quartz flour (SiO₂) serves as a skeleton-forming component and a source of silicon ions for the formation of calcium silicates (Ca₂SiO₄, CaSiO₃) [3]. In addition, its excess prevents excessive shrinkage during sintering and increases the overall thermal stability of the composite.

The main physicochemical processes expected during firing include decomposition of CaCO₃ and CaSO₄ (from gypsum) to form reactive CaO, sintering of CaO, SiO₂ and TiO₂ to form the target

crystalline phases. For example, CaTiO_3 (perovskite) is a highly stable phase. [4] Calcium silicates (Ca_2SiO_4) act as an effective mineral binder, which provides high mechanical strength to the fired material. [5]

Since quicklime and quartz flour are among the cheapest raw materials, and titanium dioxide is used in limited quantities, the cost of the final refractory promises to be significantly lower than that of high-end industrial counterparts.

Experimental studies are divided into two stages to ensure scientific reliability and minimize resources.

The goal of the first phase is to select the optimal chemical composition of the matrix and determine the temperature that provides the best sintering and maximum strength. At this stage, perlite is not used. Five target compositions have been selected for the study. Each sample of the five compositions will be fired at three different temperatures. Thus, 15 sample cubes have been produced during Phase 1.

Table 1 – list of mixture options and calculated weight of components in grams

Raw material,	CaO	SiO ₂	TiO ₂	CaSO ₄	H ₂ O
1	80	60	0	20	240
2			0	20	
3	30	55	52	20	120
4	55	0	50	20	180
5	45	20	60	20	180

After determining the strongest and most refractory matrix (S) and the optimal firing temperature (T), the second stage will begin. In it, S will be mixed with different amounts of perlite with the aim to reduce the density and thermal conductivity of the material without compromising its strength.

During sample production, quicklime, quartz flour, titanium dioxide and building gypsum were weighed according to the calculated proportions for each composition. Quicklime was slaked with water and left to react for 20 minutes until completely converted into calcium hydroxide. The main components - titanium dioxide and quartz flour - were added to the resulting lime dough. After 10 minutes of thorough mixing, gypsum was added to the mixture (approximately 10% of the mass of dry components). Gypsum acts as a technological binder, ensuring quick setting and the possibility of removing samples from the mold. The mixture was quickly poured into a square tube, the cross-sectional dimensions of which correspond to the required size of the face of the future cube. The length

of the tube allowed the formation of a solid product for further cutting. After the initial setting of the gypsum, which took 15 minutes, the still unhardened products were carefully removed from the mold and cut with a thread into identical cubes. The cubes were left to dry and carbonize naturally. This process allowed the samples to gain sufficient pre-firing strength within one day.



Figure 1 – current state of test samples.

Currently, the samples are completely dried and carbonized, ready for experimental firing.

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VIRTUAL REALITY LABORATORIES FOR STUDYING

Abstract. This paper explores the usefulness and integration of VR laboratories in the educational process, outlining their pedagogical and student-centered rationale, fundamental design principles, and methods of implementation. It also discusses key evaluation strategies, highlights real-world examples, and provides practical recommendations for deploying VR laboratories effectively in higher education and secondary schools. Special attention is given to their growing role in Material Sciences, where VR-based visualization and simulation offer new ways to understand the structure, properties, and behavior of materials.

Introduction

Education increasingly uses immersive technologies to support complex skills, spatial reasoning, and safe, repeatable practice. VR laboratories (hereafter “VR labs”) provide controlled, multi-modal experiences that can increase engagement and learning gains, particularly where hands-on labs are costly or hazardous. Systematic reviews and meta-analyses report positive effects of immersive VR on learning outcomes, although results vary by design, immersion level, and assessment method.

In the field of Material Sciences, VR laboratories offer unique opportunities for visualizing and manipulating atomic and molecular structures, crystal lattices, and microstructural phenomena that are difficult to perceive through traditional two-dimensional models [1]. Through immersive simulation, students can interact with materials at the nanoscale—exploring phase transformations, stress–strain relationships, and thermal processes in a virtual environment. Such VR-based laboratories enable learners to understand the relationship between structure, processing, and properties in a more intuitive and experiential way.

For instance, VR modules developed in materials engineering programs allow students to virtually “enter” metallic crystal lattices, observe dislocation motion, or simulate alloy solidification processes. These environments can replicate expensive or hazardous experiments such as heat treatment, fracture testing, or electron microscopy sessions, making them more accessible and safer for undergraduate study. Additionally, research in materials education has shown that VR-enhanced

visualization significantly improves students' spatial understanding and conceptual retention of microstructural behavior compared with textbook-based learning.

As a result, VR laboratories in Material Sciences not only support active, experiential learning but also foster interdisciplinary integration between materials engineering, computational simulation, and data science [2]. They represent an important step toward the development of digital twin laboratories that link real-time experimental data with virtual experimentation and predictive modeling.

From an instructional perspective, VR laboratories offer powerful pedagogical advantages that align with experiential and constructivist learning theories. First, they enable safe and repeatable practice in complex or hazardous environments, allowing learners to conduct experiments, handle virtual equipment, and observe outcomes without physical risk or material waste. This capability is particularly valuable in disciplines such as chemistry, medicine, and material sciences, where laboratory errors can be costly or dangerous.

Second, VR environments promote embodied and spatial learning, engaging multiple sensory channels and supporting cognitive processes such as spatial reasoning, procedural memory, and conceptual visualization. In material sciences, for example, students can explore crystal structures, visualize dislocation movement, or observe stress–strain relationships in three dimensions—activities that are nearly impossible to achieve with traditional tools.

Third, VR labs support equitable access to resources, democratizing learning experiences that would otherwise be limited by geography, funding, or equipment availability [3]. Virtual experiments can be distributed across institutions, providing equal opportunities for learners to engage in advanced simulations and practical exercises. This scalability makes VR a sustainable model for modern laboratory education.

From the learner's point of view, VR laboratories enhance motivation, engagement, and confidence by transforming abstract concepts into tangible, interactive experiences [4]. Students gain autonomy to explore, make mistakes, and repeat procedures at their own pace, which fosters deeper understanding and self-regulated learning. The immersive nature of VR creates a strong sense of presence, improving attention and retention of complex ideas.

In fields like material sciences, students can virtually “enter” a microstructure, observe atomic bonding or fracture propagation, and manipulate variables in real time. Such experiences not only make learning more memorable but also develop 21st-century skills such as problem-solving, collaboration, and digital literacy. Moreover, the accessibility of VR labs allows students from diverse backgrounds or remote regions to participate in laboratory-based education that would otherwise be unavailable, strengthening inclusivity and lifelong learning potential.

The success of a virtual reality laboratory depends not only on the technology it employs but also on how effectively it supports specific learning outcomes. A learning-first design approach should guide every stage of development. This means starting from well-defined learning objectives rather than focusing on the novelty of immersive technologies. The virtual scenarios must be aligned with core competencies and assessment strategies so that the digital experience genuinely enhances the intended educational goals.

Equally important is the appropriate level of immersion. Not every subject or learning activity requires a fully immersive headset-based environment. In some cases, semi-immersive or desktop-based VR can achieve similar results at lower cost and greater accessibility. The choice of immersion level should therefore reflect pedagogical purpose, available infrastructure, and the needs of diverse learners.

Another essential design element is scaffolding and feedback. VR environments are most effective when learners receive structured guidance, step-by-step prompts, and opportunities for reflection. Immediate feedback inside the virtual setting helps learners correct mistakes and build procedural understanding, while post-session debriefing allows them to connect virtual experience with theoretical knowledge.

A user-centered approach to safety and accessibility must also be integral to the design. Ergonomic considerations, clear limits on session duration, and adaptations for users prone to motion sickness or with disabilities ensure that all learners can participate comfortably. Accessibility features such as adjustable text size, voice commands, and optional non-immersive modes can make the virtual lab more inclusive [3].

Finally, sustainable implementation requires scalability and effective content management. [2] Reusable and modular content allows instructors to adapt simulations for multiple courses or disciplines. Integration with learning analytics systems provides valuable insights into student performance, while a centralized content repository supports collaboration and long-term maintenance. Together, these principles ensure that VR laboratories remain pedagogically meaningful, technically reliable, and educationally impactful.

Several universities have established dedicated VR laboratories that support visualization, collaborative design, and research [5, 6]. These facilities serve as valuable testbeds for both pedagogy and technological innovation. Case reports from course pilots and institutional programs demonstrate successful applications of VR in disciplines such as psychology, microbiology, and engineering, where virtual environments have replaced or supplemented traditional wet labs and field trips. These initiatives often show positive student engagement and, in some cases, measurable improvements in learning outcomes. Comprehensive reviews of the field indicate that VR holds particular promise in areas

such as medical simulation, engineering, and the earth sciences, while also emphasizing the need for more rigorous comparative studies and standardized methods for evaluating learning outcomes.

Virtual reality laboratories are proving particularly valuable in the field of Material Sciences, where much of the learning depends on visualizing and understanding complex structures, transformations, and microscopic processes. Traditional laboratory teaching often struggles to represent the three-dimensional nature of materials, such as crystal lattices, grain boundaries, and molecular bonding. VR environments make these invisible phenomena tangible by allowing students to explore atomic arrangements, visualize dislocation movements, or simulate heat treatment processes in real time. Through immersive visualization, abstract concepts become spatial and interactive, enabling deeper conceptual understanding and stronger cognitive retention [7].

The usefulness of VR for material science education lies not only in visualization but also in experiential learning. Students can conduct virtual experiments—testing mechanical deformation, phase transitions, or thermal conductivity—without consuming physical materials or requiring costly, specialized equipment [1]. For instance, a VR-based tensile testing simulation can demonstrate the behavior of metals under stress, allowing learners to manipulate parameters and immediately observe how microstructural changes influence mechanical properties. This experiential approach promotes active learning and allows for multiple repetitions, which would be impractical or expensive in a traditional setting.

Moreover, VR laboratories support interdisciplinary integration between materials engineering [8], computational modeling, and data analysis. By combining virtual experimentation with digital twins and simulation software, students can bridge the gap between theoretical principles and practical application. This aligns with modern trends in materials research, where computational materials science and machine learning increasingly complement laboratory work. VR tools thus prepare future engineers and scientists to operate effectively in these hybrid physical-digital environments.

At present, the implementation of VR in material sciences is still in a developing stage. A number of universities have introduced pilot projects or small-scale VR modules for topics such as crystal structure visualization, metallurgical processing, and nanomaterial characterization. Research findings indicate that such applications improve students' spatial reasoning, conceptual understanding, and engagement compared with traditional lecture-based instruction. However, widespread adoption is limited by high development costs, the need for specialized content, and a lack of standardized curricula or training for instructors. Despite these challenges, the trend toward digital transformation in laboratory education and the growing availability of affordable VR hardware suggest that virtual laboratories will soon become a regular component of materials science education.

In summary, VR laboratories play a crucial role in modernizing the study of materials by providing safe, flexible, and immersive environments that make microscopic and abstract phenomena accessible. They not only enrich current teaching practices but also prepare students for the increasingly digital and data-driven future of materials research and engineering.

CONCLUSION

VR laboratories are a maturing educational technology with clear potential where experiential practice, spatial understanding, and safe repetition matter. Successful VR labs prioritize learning objectives, scaffolded experiences, evaluation, and institutional support. Ongoing research should focus on longitudinal learning gains, cost-effectiveness, and standardizing assessment to make the strongest case for broad curricular adoption.

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USING NANOMATERIALS IN CREATING BREATHABLE WALLS FOR INTERIOR DESIGN

Abstract. The article considers the concept of an interactive breathing wall as an innovative element of interior design, combining the functions of air purification, adaptive lighting and acoustic comfort. The basis of the system is a photocatalytic nanocoating based on TiO_2 , which provides decomposition of volatile organic compounds and neutralization of odors in residential premises. The wall design includes a multilayer structure with a decorative coating, composite materials, LED optical channels and acoustic modules, which allows integrating technological functions into an aesthetically completed architectural element. The system is modular, energy-efficient and compatible with "smart home" technologies, which ensures its versatility for residential and public spaces. The use of nanomaterials in combination with modern technologies creates a healthy, harmonious and comfortable environment, meeting current trends in industrial design.

Keywords: breathable wall, nanomaterials, photocatalytic coating, titanium dioxide, air purification, adaptive lighting, interior design, smart home.

Modern trends in industrial design are increasingly aimed at creating multifunctional architectural objects that combine technological, environmental and emotional aesthetics. In the interiors of residential premises, traditional household appliances such as air purifiers, lamps, and acoustic systems often disrupt the harmony of space. The paper proposes to replace traditional household appliances used to improve the air quality of a living room with a breathable wall that solves this problem by integrating the functions of the devices into the surface of the wall itself. This allows you to create a zone of clean air, adjustable lighting and sound comfort without the use of visible devices. The article considers an innovative interactive breathable wall that combines the functions of air purification, adaptive lighting and sound atmosphere in the structure of a decorative architectural element. The basis of the system is a photocatalytic nanocoating based on TiO_2 , which provides the decomposition of volatile organic compounds and the neutralization of odors in the immediate area of the living room.

Internal LED channels create soft lighting with a “breathing” effect, and built-in micro-speakers create a spatial, unobtrusive sound background. The project is focused on integrating technological functions into an aesthetically completed interior element.

The problem of air quality in living rooms remains relevant, organic compounds, dust and microbiological particles accumulate in areas with insufficient ventilation. The need for a harmonious combination of air purity, soft light and acoustic comfort became the basis for the development of a new type of wall system.

The breathing wall system replaces three traditional elements at once - an air purifier, decorative lighting and a wall acoustic system. Its operation is silent, without the need for replaceable filters. Thanks to the photocatalytic coating, air purification occurs constantly when the light is turned on. LED lighting adapts to the user's circadian rhythm: warm shades contribute to relaxation, cold ones - to awakening. Soft, "breathing" light reduces stress and helps the body naturally regulate melatonin levels.

The acoustic system works on the principle of a "dissolved sound source" - the user hears uniform sound without a sense of direction. This can be white noise, the sounds of the sea, rain or light music. Aesthetically, the panel combines the sculptural nature of stone with the softness of waves – the visual image is associated with calm and depth. The surface has a light silky sheen, which emphasizes the texture in soft lighting.

The design of the breathing wall structure proposed in the work is shown in Figure 1, which consists of several functional layers. The outer layer is a decorative surface with a matte-silky texture of a granite-gray shade. This is a nanoceramic coating with high scratch resistance and a tactile effect of “silk”. Under it is a photocatalytic layer based on titanium dioxide (TiO_2), modified to work in the visible spectrum. Under the action of light, it decomposes organic compounds and bacteria, converting them into harmless substances. Next is a layer of wavy composite that forms the three-dimensional geometry of the wall. It is made of a lightweight reinforced polymer that performs an acoustic function – absorbs mid-frequency sounds. Inside the waves are optical channels with RGBW LED backlighting, providing the effect of "breathing" light. Behind them are microspeakers with flat membranes, which create a diffuse sound space. All this is mounted on an aluminum or composite frame with technical channels for electronics and ventilation.

The technical characteristics of the materials used for the construction of a breathable wall, which consists of several functional layers, are presented in Tables 1-6.

Analysis of the technical characteristics of the materials given in Tables 1-6 confirms the feasibility of their use for creating a multifunctional breathable wall structure. Photocatalytic nanocoating based on titanium dioxide (Table 1) provides effective decomposition of organic compounds and

neutralization of odors due to the high photocatalytic activity of the anatase modification. Its resistance to aging, exceeding 10,000 hours of ultraviolet exposure, guarantees long-term operation without loss of properties, and the optimal particle size within 15–25 nm provides the maximum active surface area.

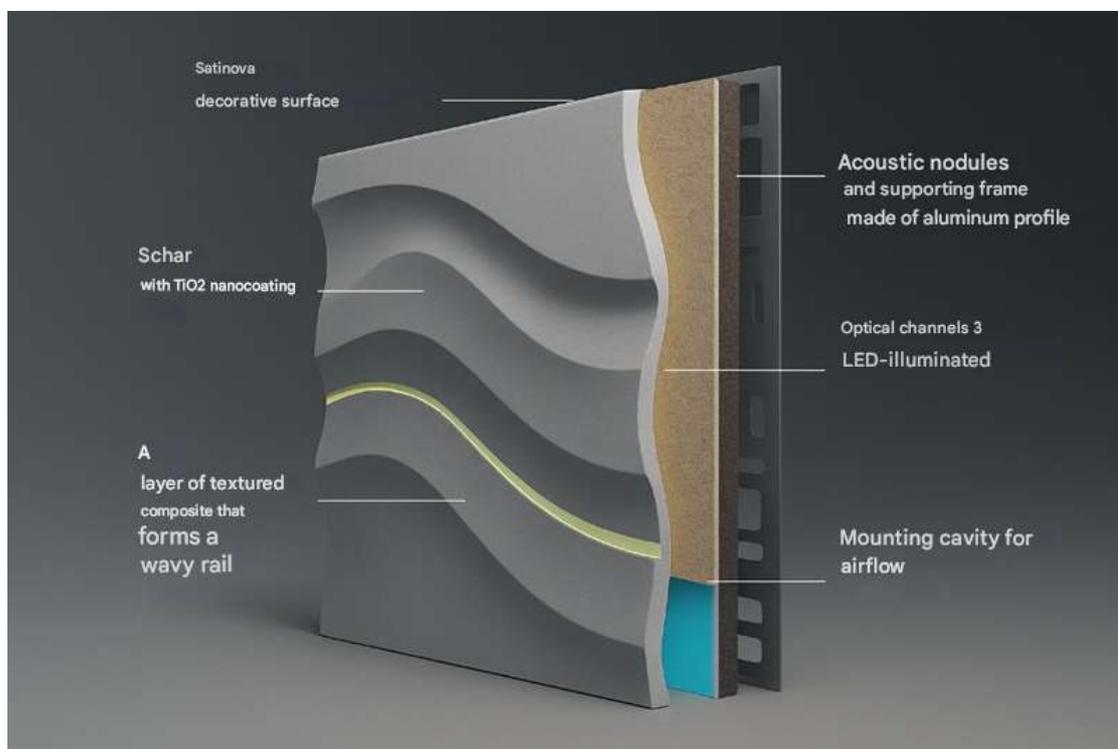


Figure 1 – Breathable wall design

Table 1 – Nanocoatings based on titanium dioxide (TiO₂)

Indicator	Value	Description
Chemical formula	TiO ₂	Anatase has higher photocatalytic activity compared to rutile, due to the larger surface area and electron excitation energy
Average particle size	15–25 nm	Optimal range for maximum surface area to volume ratio.
Structure	Tetragonal	Stable at temperatures < 600 °C, does not change structure during operation.
Optical activity	UV-A (365–400 nm)	Stimulates the decomposition of organic compounds and volatile components.
Surface energy	72 MJ/m ²	Provides strong adhesion to polymer and mineral substrates.
Mohs hardness	5,5–6	Sufficient for scratch resistance during operation.
Aging resistance	> 10000 hours of UV exposure	Retains activity, does not undergo structural degradation.

Table 2 – Textured composite layer (structural base)

Indicator	Value	Description
Composition	Polymer matrix (EPDM / PU) + SiO ₂ microspheres	Combines the elasticity of polymers and the structural stability of mineral additives.
Density	1605–162 g/cm ³	Lightweight material that does not overload the load-bearing wall.
Modulus of elasticity (E)	50–80 MPa	Elastic deformation during microvibrations, well dampens sound.
Thermal conductivity	0,18 W/m·K	High thermal insulation properties.
Porosity	8–12% (open)	Promotes the “breathing” effect of the wall, allowing water vapor to pass through.
Sound absorption coefficient (α_w)	0,55–0,75	Increased acoustic damping in the mid-frequency range.
Chemical resistance	Resistant to weak acids and alkalis	Does not collapse under the influence of household detergents.

Table 3 – Satin decorative surface (outer layer)

Indicator	Value	Description
Material	Fiberglass with a polymer satin coating	Combination of the rigidity of fiberglass and the optical softness of satin.
Texture	Matt satin, diffuse light scattering	Diffuses light, masks LED sources.
Light transmission	60–70%	Optimal for interior lighting.
Coating hardness	3H (ASTM D3363)	Resistant to scratches from everyday contact.
Layer thickness	1,5–2 mm	Provides mechanical rigidity without overload.
Coefficient of thermal expansion	$8 \times 10^{-6} 1/^\circ\text{C}$	Minimal deformation when changing temperature.
Moisture resistance	up to 95 % RH	Does not absorb water, does not become cloudy over time.

Table 4 – LED optical system and electronic components

Indicator	Value	Description
Diode Type	SMD 2835 / UV-A 365 nm	The wavelength activates TiO ₂ without harm to humans.
Substrate	Aluminum plate	Provides heat dissipation, reduces crystal degradation.
Heat Transfer Coefficient	190 W/m ² ·K	Guarantees stable operation during continuous operation.
Housing Material	Polycarbonate (PC) with UV protection	Resistant to heating and photodestruction.

Table 5 – Supporting frame and mounting base

Indicator	Value	Description
Profile material	Aluminum alloy 6063 T5	Has a high modulus of elasticity and corrosion resistance.
Tensile strength	190–220 MPa	Ensures structural stability under loads.
Anti-corrosion coating	Anodizing $\geq 15 \mu\text{m}$	Increases resistance to moisture and atmospheric factors.
Construction weight	$\approx 5\text{--}6 \text{ kg/m}^2$	Lightweight construction that does not require reinforced fastening.
Mounting cavity	30–50 mm	Allows integration of cables, sensors and acoustic modules.

Table 6 – Acoustic layer (optional component)

Indicator	Value	Description
Material	Perforated polyester + PET fiber	Lightweight, open-pore sound-absorbing material.
Sound absorption coefficient (α_w)	0,6–0,8	Absorbs mid and high frequencies.
Fiber density	40–60 kg/m^3	Provides a balance between acoustics and mass.
Environmental friendliness	100% recycled PET	Complies with EN 13501 and LEED standards.

The textured composite layer (Table 2) is characterized by a low density of 1,05–1,2 g/cm^3 , which does not overload the supporting structure, and a high sound absorption coefficient ($\alpha_w = 0,55\text{--}0,75$), which, together with a porosity of 8–12%, creates acoustic comfort and contributes to the “breathing” effect of the wall. Chemical resistance to household products ensures the durability of the material. The decorative satin surface (Table 3) performs the function of diffuse light scattering, masks LED backlight sources and creates a soft visual effect. It has high resistance to moisture (up to 95% RH) and scratches (hardness 3H), which guarantees the preservation of aesthetics for a long time.

The LED optical system (Table 4) activates the photocatalytic layer using UV-A diodes with a wavelength of 365 nm, which is safe for humans, and the aluminum substrate provides effective heat dissipation and stability of the system. The aluminum frame (Table 5) is characterized by high tensile strength (190-220 MPa) and anti-corrosion anodizing, which guarantees stability and durability with minimal weight (about 5-6 kg/m^2), simplifying installation without the need for reinforced fastening. The additional acoustic layer (Table 6), made of perforated polyester and PET fiber, provides a sound absorption coefficient of 0,6-0,8 in the mid- and high-frequency range, and its environmental friendliness meets modern standards of sustainable design.

Thus, the combination of TiO₂ nanocoating, composite and decorative materials, as well as integrated LED and acoustic systems allows you to create an energy-efficient, environmentally friendly and aesthetically attractive design of a breathable wall. Such a system provides air purification, adaptive lighting and acoustic comfort without the use of separate household appliances, which corresponds to modern interior design trends.

The breathable wall system is controlled via a smart controller that integrates into the “smart home” network. The smart controller is an intelligent module that provides interaction between the user and the system, allowing full control over all wall functions – lighting, air purification, acoustic effects and operating modes. Its software environment can be implemented in the form of a mobile application, touch panel, or integrated with voice assistants. In the case of autonomous use, the system has a separate remote control, which allows you to change modes without connecting to the Smart Home network.

Several main operating modes of the breathable wall are provided. Eco mode is activated during the day when there is natural light. The minimum backlighting on supports the photocatalytic activity of the TiO₂ nanocoating, ensuring air purification without additional energy costs. Night cleaning mode is used at night or when there are no people in the room. In this mode, the full spectrum of LEDs is activated, which stimulates the decomposition of volatile organic compounds and neutralizes unpleasant odors. “Deep Luxe” mode combines air purification with adjustable lighting and acoustic effects. The user can choose a warm or cold shade of light, creating an atmosphere of comfort and relaxation. Individual mode allows you to adjust the intensity of the backlight, the frequency of “breathing” of the light, or completely disable the cleaning function, leaving only an aesthetic effect. The system is equipped with humidity, air quality and CO₂ level sensors. These elements allow you to automatically adjust the intensity of the wall's operation according to the current microclimate, ensuring the optimal balance of energy consumption and cleaning efficiency.

The design of the breathable wall is modular and can cover the entire wall or just a part of it, for example, the area above the headboard. The panels are manufactured in standard formats of 600×1200 mm or 1200×2400 mm, which allows you to adapt the design to any space. The surface can be integrated into a “smart home” and synchronized with lighting, climate or music systems.

The breathable wall has a number of advantages that distinguish it from traditional microclimate cleaning and control systems. First of all, it is silent and fully integrated into the space. Unlike dehumidifiers, ionizers or air purifiers, the design does not contain fans and moving mechanical elements, thanks to which it operates completely silently. This is especially important for relaxation areas, such as bedrooms. The high energy efficiency of the system is due to the principle of photocatalytic cleaning. The process of activating the TiO₂ nano-coating occurs even at the minimum intensity of

LED lighting, which reduces electricity consumption. Another significant advantage is durability. Unlike devices with filters or consumables, the photocatalytic coating does not require replacement, maintaining its effectiveness throughout its entire service life. From an aesthetic point of view, the wall does not take up space and does not violate the compositional integrity of the interior. The system can adapt to any size of the room, become both an accent panel and part of the general wall. In addition to cleaning, the system performs the functions of lighting and acoustic correction of the space, providing multifunctionality and replacing several household appliances at once. This approach allows you to create an aesthetically clean, technologically rich space without overloading it with technical elements.

The breathable wall system has a wide range of applications due to the combination of the functions of air purification, lighting and acoustic stabilization of the space. Its versatility and adaptability to various architectural and design solutions allow it to be used both in residential and public spaces. Figure 2 shows examples of interiors for the use of breathable walls (a) in residential interiors, (b) in public spaces, (c) in offices.



Figure 2 - Examples of interiors for the use of breathable walls: a) in residential interiors, b) in public spaces, c) in offices

The work offers the following examples of using a breathable wall. A breathable wall in residential interiors (Fig. 2, a) is most often installed in bedrooms, living rooms, offices or relaxation areas. In bedrooms, it ensures that the air is clean during sleep, eliminating volatile organic compounds, dust, allergens and odors. In the living room, it acts as a decorative element, which at the same time works as a source of soft mood lighting, creating an atmosphere of comfort. In a home office or work area, the system improves the microclimate, reduces the amount of harmful compounds emitted by office equipment, and at the same time serves as a source of adjustable light conducive to concentration.

In public spaces (Fig. 2, b) it can be integrated into the interiors of hotels, spa complexes, restaurants, beauty salons, medical or health centers. In such institutions, it improves air quality, reduces the concentration of bacteria and odors, provides pleasant background lighting and emphasizes

the aesthetics of the space. In waiting or relaxation areas, the wall can also act as an acoustic damper, absorbing excess sound waves.

In office spaces and business centers (Fig. 2, c), the system creates a comfortable working environment by neutralizing the accumulation of CO₂ and other pollutants that often occur in air-conditioned rooms. It can also be integrated into meeting rooms as a decorative and technological element that combines light, acoustics and air purification. The breathable wall can also be used in the premium segment in “luxury” architectural projects – private residences, designer apartments and boutique hotels. Its ability to adapt to any size, shape or shade of the surface makes the system not only functional, but also artistically unique. In addition, the wall design allows it to be used in complex “smart home” systems, where it can interact with other devices – climate control systems, lighting or audio environments. Thus, Air Wave Wall becomes not just an element of the interior, but part of an integrated ecosystem that forms a new level of comfort and aesthetics in modern space.

The use of nanomaterials in the creation of breathable walls for interior design is an example of the synthesis of technologies and materials in industrial design. It creates a healthy, aesthetic and harmonious environment, combining photocatalytic air purification, adaptive lighting and acoustic comfort. Thanks to nanomaterials, a well-thought-out multilayer structure and aesthetic form, this wall becomes not just a decorative element, but an active component of the environment, improving the quality of life of the user. The use of environmentally friendly and durable materials meets modern standards of sustainable design. Thus, a breathable wall based on nanomaterials forms a healthy, harmonious and technologically rich environment for residential and public interiors.

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DESIGN OF A TRANSFORMER SHELF USING ECO-MATERIALS

Abstract. The article presents a project of a transforming shelf, which was developed for the needs of modern compact storage space planning. The design is based on the principles of modularity, environmental friendliness and ergonomics, which ensures its adaptability and functionality. A 3D model of the transforming shelf was built, which allowed us to present in detail the proposed design, its shape and connection of elements. The use of environmentally friendly materials is proposed for the manufacture of the design. A modern technology for manufacturing the product is proposed, which will ensure high accuracy of product manufacturing. The shelf is easily assembled without tools and can be adapted to various interiors. The project has a wide range of applications from residential premises to offices and educational institutions.

Keywords: transformer shelf, modularity, ergonomics, eco-materials, 3D-modeling, functionality, adaptability

The modern furniture market is changing rapidly, and designers are increasingly turning to the ideas of flexibility, adaptability and multifunctionality [1-2]. Transformable furniture has become an important trend in world design [3], as evidenced by the works of famous designers such as Karim Rashid, Philippe Starck and Jasper Morrison. Their works show the desire to create objects that not only decorate the interior, but also effectively use space, responding to the needs of the user [4-5].

The work proposes a project for a transforming shelf, which the authors called “Smart Shelf”, is a response to the modern challenge of urban life, where every square meter matters. The idea is to create a storage system that can be easily adapted without tools, changing the configuration to suit your needs. The principles of modularity, ergonomics and environmental friendliness are at the heart of it, combining functionality and accessibility.

The article shows 3D models of the transforming shelf developed in the Blender 3D program, which allowed for detailed study of the shape, connections and proportions of the elements (Fig. 1). This provided accurate visualization of the structure, as well as the ability to evaluate its appearance

in various interior scenarios. The transforming shelf design offers ease of assembly, minimalist aesthetics and ergonomic design.

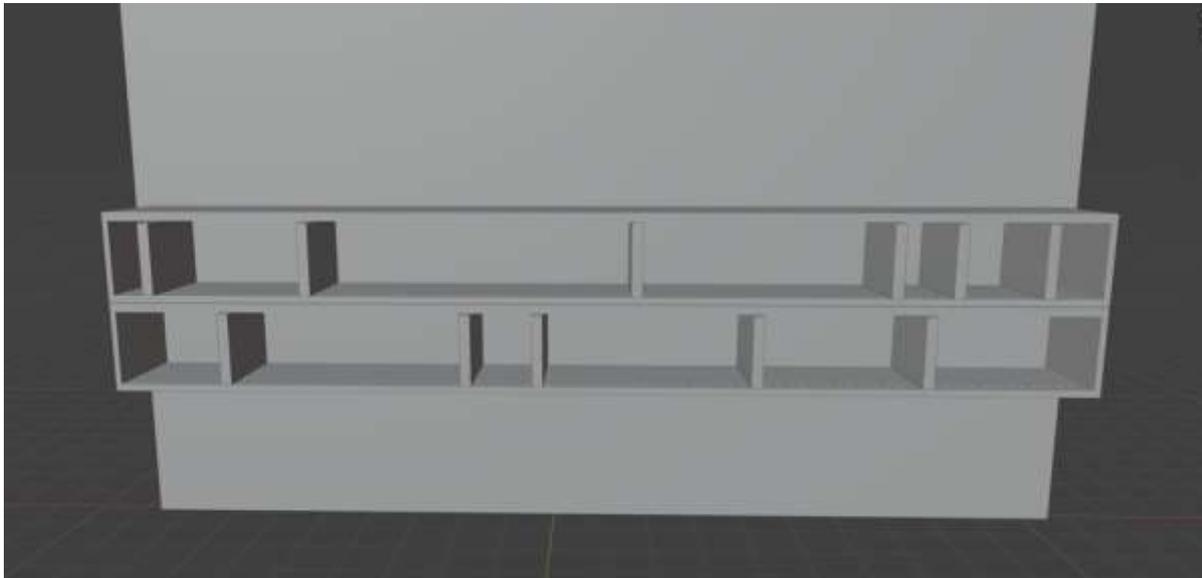


Figure 1 – 3D-model of the transformer shelf “Smart Shelf”

The modern furniture market requires innovative solutions that combine functionality, ergonomics and environmental friendliness. The “Smart Shelf” transforming shelf design is proposed as a response to these challenges. The main idea is to create a universal storage system that allows you to adapt the internal space to the individual needs of the user without the need for additional tools or complex processing. The concept is based on the principles of modularity and flexibility. Each element of the cabinet is designed to provide maximum functionality with minimal space requirements. It is also proposed to use environmentally friendly materials for manufacturing, which emphasizes a responsible approach to production and the environment.

The transforming shelf consists of several key components that are simple and convenient to use. Figure 2 shows a 3D model of the shelf wall, which proposes a convenient and easy-to-use “spike” fastening, which shows the principle of screwless connection. This solution makes the shelf convenient for transportation and quick assembly.

For the manufacture of the transforming shelf, it is proposed to use environmentally friendly material. The frame is made of bamboo or birch plywood, which provides lightness and strength. The dimensions of the transforming shelf are as follows: shelf height 180-200 cm, width 60-80 cm, but these dimensions can be modified to suit the individual needs of users.

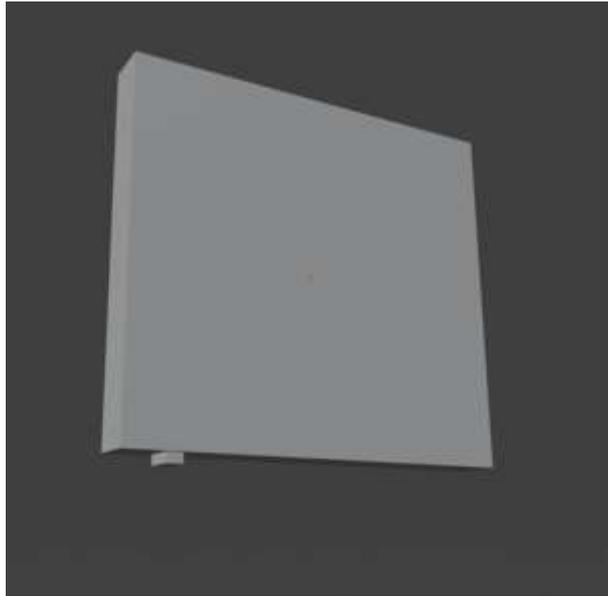


Figure 2 – 3D model of the partition of the transforming shelf with a “spike” fastening

The walls of the shelf are equipped with spikes that precisely fit into the grooves on the side-walls of the frame, which allow you to adjust the depth from 15 to 50 cm depending on your needs. The material of the walls is proposed to be made of durable plywood with a natural latex coating to increase wear resistance. The fastening system in the form of grooves is designed to ensure smooth movement of the shelves without the use of additional tools. The “spikes” have a special rectangular shape that prevents spontaneous separation [6]. The type of holes for fastening the shelf walls, the “tongue”, provide precision joints, which is achieved through laser cutting, is shown in Figure 3.



Figure 3 – View of the holes for the partitions of the transforming shelf for the “spike” fastening

In the design of the transforming shelf, it is proposed to use environmentally friendly and affordable materials that have high strength, moisture resistance and wear resistance, such as bamboo, birch plywood, MDF, PLA plastic, metal inserts [7]. The technical characteristics of the proposed material for the manufacture of the transforming shelf and their environmental friendliness are presented in Table 1.

Table 1 – Technical characteristics of the material and environmental performance indicators

Material	Density (g/cm ³)	Strength (MPa)	Moisture resistance	Hardness	Ecology
Bamboo	0,65-0,75	80-100	High	Average	100% natural
Birch plywood	0,55-0,70	60-90	Average	Average	Environmental
MDF	0,65-0,80	45-70	Average	Low	Safe for varnishing
PLA Plastic	1,25	50-65	Low	High	Biodegradable
Aluminium	2,70	200-250	High	High	Recyclable metal

The use of plywood and MDF makes the shelf cheap to manufacture, but at the same time it looks modern and reliable. Using bamboo can be an option for the premium segment.

For the manufacture of the Smart Shelf transforming shelf, modern technology is proposed, which combines precise cutting and environmentally friendly materials. The main goal of the proposed design is to minimize costs while maintaining high quality and durability of the product. It is proposed to use laser cutting technology, which provides accuracy up to 0,1 mm. It is ideal for creating complex grooves and tongue-and-groove joints. This makes it possible to manufacture parts without additional grinding. You can also use 3D printing technology, which can be used to create unique fasteners, latches and decorative elements. And it will allow you to personalize the shelf for a specific user. The next stage of the shelf manufacturing technology is mechanical processing (milling, grinding), which is used for finishing surfaces, which improves the quality of joints and the appearance of the product. The key technological properties of the materials used in the design and their purpose for the parts of the transforming shelf are shown in Table 2.

The transforming shelf can be used in many areas, such as residential premises, small apartments, student dormitories, country houses, offices and business spaces, co-working spaces, libraries, exhibition areas, specialized premises, workshops, medical institutions, educational centers. The project options are provided for a variety of types of design and color solutions to various materials and natural shades of wood, which add bright accents to modern interiors. The design can also use additional functions such as built-in lighting, mirror surfaces, magnetic panels for notes. Dimensional

options can also be different with different options, where additional modular floor and wall modules and corner structures can be offered to the transforming shelf.

Table 2 – Material processing technology and their purpose for parts of the transforming shelf

№	Material	Trim type	Advantages	Estimated cost	Note
1	Bamboo	Laser cutting, varnishing	Lightweight, durable, eco-friendly	Average	The best option for the case
2	Birch plywood	Milling, grinding	Durable, easy to handle	Cheap	Best value for money
3	MDF	Cutting, painting	Smooth surface, easy to paint	Very cheap	Suitable for budget series
4	PLA Plastic (3D Printing)	Printing + Grinding	Eco-friendly, precise	Available	For small parts and fasteners
5	Metal inserts (aluminum)	Cutting, polishing	Strengthens the structure, adds style	More expensive	Used to a limited extent

In general, the proposed design is economically and environmentally feasible, production is focused on minimal costs without loss of quality.

Functional advantages of the transforming shelf design – adaptability, the ability to change the configuration in a matter of minutes compared to traditional shelves. Suitable for storing items of various sizes - from books to large appliances. Ergonomic advantages of the transforming shelf design – optimal use of space due to adjustable shelves, convenient access to all levels. Environmental advantages of the transforming shelf design – use of biodegradable materials, minimal carbon footprint during production. Economic advantages of the transforming shelf design – replaces several conventional shelves and long service life thanks to high-quality materials.

Conclusion. The project of the transforming shelf “Smart Shelf” presented in the work is a relevant solution for the modern urban environment, where the efficient use of space is of crucial

importance. The design of the transforming shelf combines the principles of modularity, ergonomics and environmental friendliness, which ensures its functionality, aesthetics and accessibility. Thanks to the use of environmentally friendly materials, such as bamboo, plywood, MDF and PLA plastic, a balance between stability, durability and environmental responsibility is achieved. The proposed manufacturing technologies allow for the manufacture of parts with high precision, which simplifies the process of assembly and personalization of the product.

The proposed 3D-model of the transforming shelf design is easily adapted to the user's needs without the use of tools, which makes it convenient for a wide range of consumers. It can be used in various types of premises, from small apartments to offices and educational institutions. The use of additional functions, such as lighting, mirror surfaces and magnetic panels, expands the functionality of the shelf. The economic feasibility of the design lies in minimizing costs while maintaining high quality. In general, the design of the transforming shelf "Smart Shelf" is an example of modern furniture design that combines innovation, functionality, economy, environmental friendliness and practicality in manufacturing.

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MATERIALS SCIENCE ASPECTS OF CREATING ENVIRONMENTALLY FRIENDLY WATER-REPELLENT MATERIALS FOR WATERPROOF CLOTHING USING BIONIC PRINCIPLES

Abstract. The article is devoted to the analysis of the material science aspects of creating ecological water-repellent materials for waterproof clothing based on bionic principles. The bionic principle of water repellency is considered as an example of natural superhydrophobicity and its use in the development of modern textile materials. Modern coating technologies and their environmental limitations are analyzed, in particular the risks of using fluorinated compounds. A modernized three-layer design of waterproof clothing is proposed, which combines an outer protective layer, an ePTFE membrane and a bio-synthetic insulation made of recycled fibers. Such a system provides waterproofness, vapor permeability, thermal insulation and environmental friendliness, which meets modern requirements for functional clothing. The results of the study demonstrate the prospects for implementing bionic principles in materials science to create multifunctional textile materials.

Keywords: water-repellent materials, bionic principles, waterproof clothing, ePTFE membrane, bio-synthetic insulation, ecological materials.

The lotus effect is an example of natural superhydrophobicity, which provides extremely low surface wettability due to the micro- and nanostructures of plant leaves. Modern research is aimed at creating environmentally friendly materials that combine waterproofness, vapor permeability, and wear resistance without the use of fluorinated compounds [1]. The purpose of the article is to show the use of bionic principles in materials science, which opens up prospects for the development of multi-layer systems for waterproof clothing with high operational and environmental characteristics.

The effect of extremely low surface wettability can be observed on the leaves and petals of plants of the genus Lotus, and other plants, such as krasola, common reed, etc. Water that falls on the surface of the leaves condenses into spherical droplets. As water flows off a leaf, it also carries dust particles with it, thus cleaning the surface of the plant. The wings of butterflies and many other insects

are designed in a similar way, for which protection from excess water is vital; if they get wet, they would lose their ability to fly [2].

The lotus effect was discovered by German botanist Wilhelm Barthlott in the 1990s, although the properties of lotus leaves have been known for a long time. One practical direction for studying this effect is the creation of so-called superhydrophobic materials. A superhydrophobic material is a material that has an extremely high water repellency, causing water droplets to roll off the surface quickly without being trapped or leaving a residue [3]. Figure 1 shows the main theoretical models – the Wenzel and Cassie–Baxter models.

In the Wenzel state, the liquid penetrates into the roughness, the contact area increases – increased adhesion. In the Cassie–Baxter state, air is trapped under the droplet in the roughness, the contact area is smaller – very low adhesion and rolling of the droplet. The transition between the states, the stability of the Cassie state and the conditions for its preservation are a key theoretical and experimental topic.

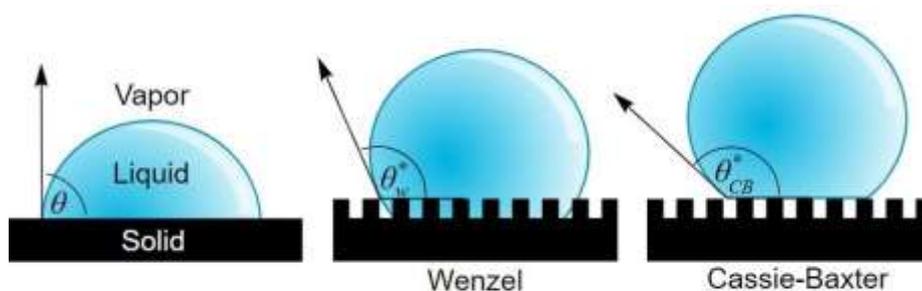


Figure 1 – The Cassie-Baxter model and the Wenzel model

The development of materials with self-cleaning properties is based on bionic principles that reproduce the lotus effect. To achieve high water repellency, structured surfaces with fluorochemical or silicone coatings, as well as compositions with microparticles, are used. Such technologies are used in the production of fabrics, paints, tiles, as well as to protect technical surfaces, in particular antennas, from moisture and icing. The main problems remain the environmental risks of fluorinated compounds and the reduction in the effectiveness of coatings during mechanical wear or exposure to chemical agents. Promising areas of development include the creation of durable self-healing systems, transparent coatings for optics and solar panels, as well as environmentally safe formulations without fluorinated components.

The lotus effect made it possible to create lightweight, breathable and water-repellent clothing that provides comfort even in adverse weather conditions. Waterproof clothing is widely used in everyday life (jackets, raincoats, raincoats), in sports and hiking equipment, as well as in special clothing

for rescuers, military personnel, and workers who work outdoors. But despite its numerous advantages, the article proposes an updated design for waterproof clothing.

The work was based on the classic three-layer fabric system of the GORE-TEX type [4-5], which is widely used in the production of highly functional protective clothing. This construction consists of an outer protective layer with a DWR water repellent coating, an ePTFE membrane and an inner lining. Table 1 describes the physical and mechanical properties of ePTFE.

Table 1. Physical and mechanical properties of ePTFE

Property	Characteristic
Waterproofness	1000-28000 mm
Vapor permeability	~20000 g/m ² /day
Windproofness	1,0 CFM
Thermal conductivity	~0,25 W/(m·K)
Tensile strength	20–40 MPa
Density	2,1–2,3 g/cm ³
Abrasion resistance	High
Resistance to ultraviolet light	High
Chemical resistance	High
Hydrophobicity (wetting angle)	110–115°
Durability	>10 years

This system provides waterproofness, windproofness, and vapor permeability, but it does not take into account modern requirements for thermal insulation, environmental friendliness of materials, and multifunctional clothing design [6]. Therefore, the paper proposes to modernize the design of waterproof clothing, preserving the basic principle, but updating the composition of the layers in accordance with modern needs (Fig. 2).

Figure 2 shows that the first layer in the proposed updated waterproof clothing system is an outer protective material with a water-repellent coating. It is advisable to use polyamide or polyester as the base. These synthetic fibers have high abrasion resistance, resistance to ultraviolet and mechanical stress, and also retain flexibility at low temperatures. The surface coating ensures that water droplets roll off the surface of the fabric and prevents it from getting wet. Thus, the first layer performs protective, decorative and environmental functions, preserving the appearance and increasing the wear resistance of the product.



Figure 2 – Updated waterproof clothing desing

The second layer remains the ePTFE membrane, which is the core of the GORE-TEX system. During production, the membrane expands, forming a microporous structure with pores of about 0,2 mm. Such pores are too small for water droplets to pass through in a liquid state, but large enough for water vapor molecules to diffuse from the inside, providing a combination of waterproofness and vapor permeability. Figure 3 shows the principle of operation of the membrane, the blue arrow is water or drops, the orange arrow is moisture (sweat).

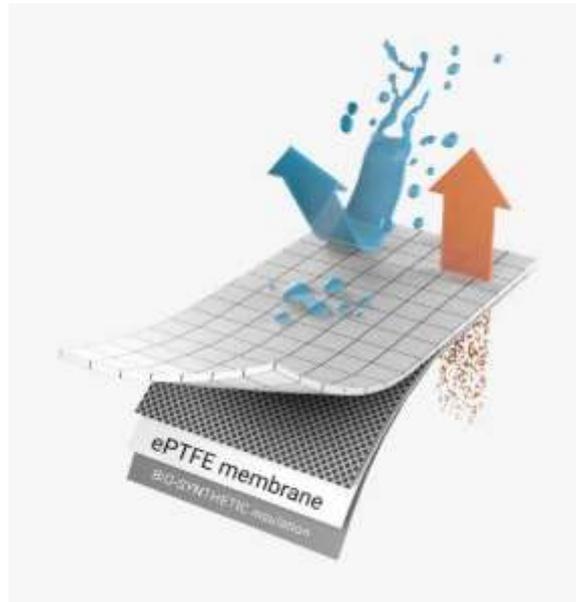


Figure 3 – Illustration of membrane operation: blue arrow – water or drops, orange arrow – moisture (sweat)

The membrane is also windproof, chemically inert, resistant to a wide range of temperatures and mechanical loads. It is because of the unique combination of protective properties and durability that ePTFE is retained as the main functional layer in the updated proposed waterproof clothing design. Table 2 describes the chemical composition and structural characteristics of ePTFE.

Table 2. Chemical composition and structural characteristics of ePTFE

Parameter	Description
Full name	Expanded polytetrafluoroethylene
Main elements	Fluorine, Carbon
Polymer type	Linear fluoropolymer
Structure	Microporous (pores ~0,2 μm)
Chemical inertness	Very high
Biocompatibility	High

The main innovation in waterproof clothing is the proposal to replace the traditional inner layer with a highly efficient BIO-SYNTHETIC insulation. BIO-SYNTHETIC insulation is made from

100% recycled fibers that are biodegradable in nature and when released into the natural environment, they decompose under the action of microorganisms without forming microplastics [7]. Structurally, the insulation consists of thin microfibers, between which up to 96% of air cavities are formed, which provides excellent thermal insulation. Unlike classic GORE-TEX, which does not contain a thermal insulation layer, it is proposed to add a modern bio-synthetic insulation such as Primaloft Bio or Dupont Sorona, which combines high thermal insulation with environmental friendliness. This combination of materials provides effective protection against water, wind and cold while maintaining the breathability of the fabric. As shown in table 3, bio-synthetic insulations have low thermal conductivity, retain air well, retain heat even when wet, dry quickly, and have high elasticity. Unlike natural down, they are moisture-resistant and easier to care for, and unlike conventional synthetics, they are environmentally friendly.

Table 3. Properties of BIO-SYNTHETIC insulation

Parameter	Description
Composition	100 % recycled polyester + biodegradation enhancers
Thermal conductivity	0.030–0.040 W/m·K
Air content	≈ 90–96 %
Elastic recovery	High
Biodegradability	Up to 93 % (ASTM D5511)
Hypoallergenic	Yes
Eco-certification	100 % recycled, PFC-free finish

As an alternative for waterproof clothing, you can consider natural down or conventional synthetic insulation without bio-additives, but they have a number of disadvantages - down loses its properties when wet and can cause allergic reactions, and traditional synthetics do not decompose in nature and cause the formation of microplastics. Instead, BIO-SYNTHETIC insulation combines high thermal insulation, moisture resistance, environmental friendliness and hypoallergenicity, making it the optimal solution for modern functional clothing. Thus, the proposed design of waterproof clothing

combines three highly functional layers, each of which performs its own distinct role: the outer layer protects and repels water, the membrane provides waterproofness and breathability, and the BIO-SYNTHETIC insulation is responsible for thermal protection and environmental friendliness. This allows you to create modern clothing that is simultaneously warm, lightweight, breathable, waterproof, wear-resistant, and environmentally friendly.

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ENGINEERING SOLUTIONS AND CHOICE OF MATERIALS FOR THE MULTIFUNCTIONAL FURNITURE MODULE-TRANSFORMER «SOFA-TABLE»

Abstract: The design of the “Sofa-Table” module is studied for the effective use of limited space. An engineering solution with inclined grooves for automatic transformation of integrated poufs is proposed. The use of natural wood, aluminum alloy 6061-T6 and natural latex, as well as their alternatives, is analyzed, with an emphasis on durability, strength and environmental friendliness.

Keywords: Transforming furniture, ergonomics of space, multifunctional module, inclined grooves, natural materials, aluminum alloy.

The concept of developing a multifunctional furniture module “Sofa-Table” is aimed at creating a transformer that can effectively function as a full-fledged sofa when folded and as a table with two integrated poufs when unfolded. This innovative solution allows you to replace three separate pieces of furniture, which is especially valuable for small-sized housing, studios, as well as flexible office environments and coworking spaces, where modularity and speed of change of functional areas are valued.

The structural basis of the module is a box with rounded corners, which performs the function of a load-bearing body, providing the necessary structural rigidity. The seat of the module contains poufs with legs that interact with specially milled inclined grooves in the seat plate. The key engineering solution is the pouf transformation mechanism, which provides smooth, controlled and automatic lowering of the poufs when transforming into a table and, accordingly, their lifting for the sofa mode, eliminating the need for manual removal. The backrest, leaning forward, precisely closes the niche from the poufs, forming a perfectly flat surface of the tabletop. To increase functionality, the tabletop can be equipped with a hinged or folding mechanism to increase its area due to the side flaps. The use of modern lifting mechanisms guarantees rigid fixation of the tabletop without backlash, which is a critical parameter for the safety and stability of the module in the working position.

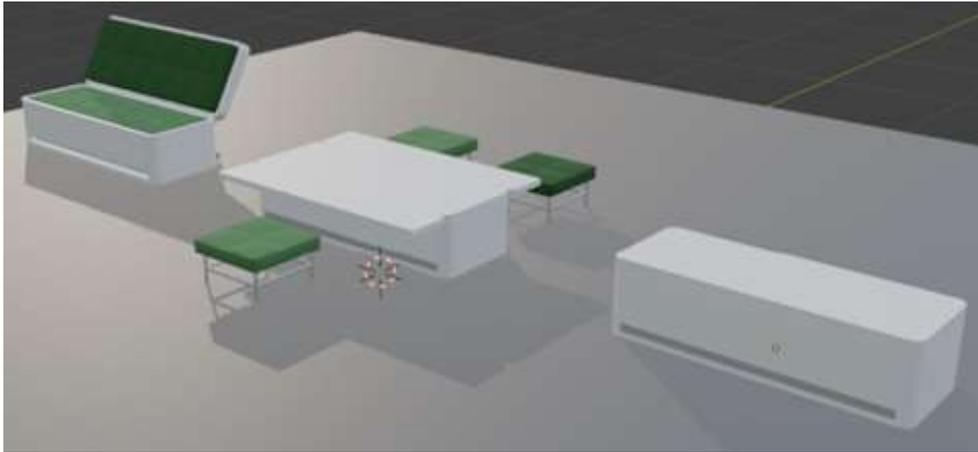


Figure 1 – General view of the transforming furniture module “Sofa-Table”

The recommended dimensions for this design are: a body length of 1600–1800mm, a depth of 700–800mm and a seat height of 400–450mm, with a total height to the backrest of 800–900mm. The ottomans are 500–550mm wide and deep and 400mm high, including the legs, which can be 50–100mm high. The inclined grooves in the seat plate are 10–20mm wider than the diameter of the legs for easy movement and the length of the inclined part is 150–250mm at an angle of 10–15° to ensure that the ottomans slide down or rise smoothly.

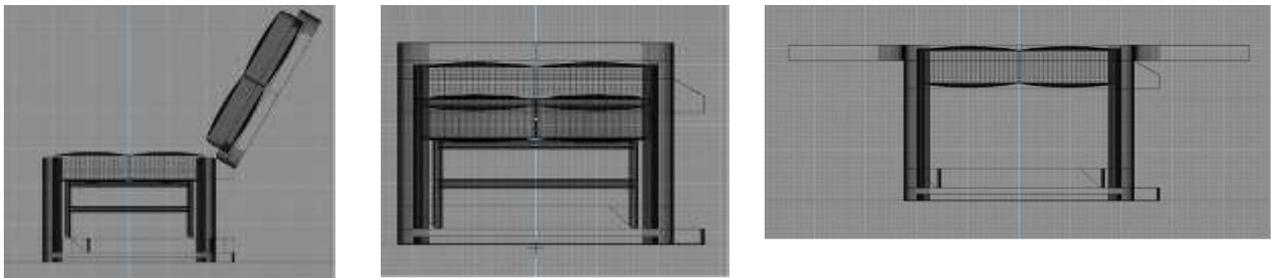


Figure 2 – layout options for the “Sofa-Table” transformer module

The choice of materials for the body and load-bearing elements of the multifunctional “Sofa-Table” module is critical to ensuring its structural rigidity, resistance to cyclic transformation loads and overall durability. The priority choice is natural hardwood, in particular oak, beech, ash and walnut. This choice is justified by a set of high physical, mechanical and environmental characteristics. For example, oak is distinguished by a high density in the range of 650–800 kg/m³ and demonstrates exceptional mechanical strength and hardness, which is a necessary condition for a furniture frame. The main advantage of wood is its environmental friendliness, non-toxicity and aesthetic appeal, which increases the overall value of the final product.

In the context of cost and weight optimization, consider alternative wood-based materials. One option is birch plywood (glued wood), which, thanks to the cross-laying of veneer layers, provides

high dimensional stability, significant bending strength and is significantly cheaper and lighter than solid wood. This makes it suitable for interior structural panels, including the seat panel, where inclined grooves for the ottoman transformation mechanism need to be milled. Another environmentally friendly alternative is bamboo panels, which are highly renewable and have an attractive, modern texture, but their higher cost limits their use.

In addition, there are a number of effective engineered wood-based and polymer-based materials that offer better cost-effectiveness, dimensional stability and ease of processing, but have certain environmental and mechanical limitations. These include wood-based composites: high-density laminated particleboard (LDSP) and medium-density fiberboard (MDF). LDSP, made of chips pressed with synthetic resins, is the most budget-friendly option with high rigidity and stability (density can reach 650–750 kg/m³), but its main disadvantage is the potential release of formaldehyde and low moisture resistance at the ends. MDF is made of fine fibers, which provides high strength and, especially important for complex designs, ease of milling and edge finishing, making it ideal for rounded body corners and grooves. However, MDF is more expensive compared to particleboard and is significantly heavier.

Polymer and composite materials can also be used for functional elements, such as HPL Compact, which has exceptional moisture, impact and wear resistance, but its very high cost limits its use to countertops or individual panels. Fiberglass reinforced plastic (FRP) offers a high strength-to-weight ratio and absolute moisture resistance, as well as the ability to form complex geometries by molding, but its high production cost and difficulty in recycling make it impractical for mass production. The choice of body material therefore requires a compromise between strength/durability targets, aesthetics and economic feasibility, with the combined use of MDF and high-density fiberboard being the most technologically and economically viable solution for mass production.

To ensure reliable functionality of the sliding system in inclined grooves and the overall stability of the furniture module, the choice of material for the legs of the poufs is important. The main material chosen is aluminum alloy 6061-T6, which belongs to heat-strengthened alloys and has optimal physical and mechanical properties, in particular, a relatively low density (2700 kg/m³), which helps to reduce the total weight of the module, while maintaining high tensile strength (290 MPa) and the necessary hardness. In addition, aluminum is highly recyclable, which meets modern principles of sustainable development. However, the cost of the product when using the specified alloy will be higher compared to ordinary carbon steel, and high-quality weldability requires the use of specialized technologies, such as TIG or MIG welding, which increases production costs.

For the convenience of the furniture module and ensuring its environmental profile, a careful approach to the selection of materials for its soft parts, including filler and upholstery, is important.

The main material for filling (seat, back, poufs) is proposed to be a combination of natural latex and coconut coir, since this combination provides high elasticity and elasticity (properties of latex) and at the same time the necessary rigidity and orthopedic effect (due to coir). The main disadvantage of this solution is a significantly higher cost compared to synthetic analogues. A much more budget alternative to natural filler is highly elastic polyurethane foam (HR-Foam), which has good elasticity and durability, although it is inferior to latex in terms of environmental friendliness and breathability.

For upholstery, it is proposed to use linen or cotton textiles, as these materials have excellent characteristics of natural fibers and provide high breathability. The main advantages of natural upholstery are environmental friendliness, hypoallergenicity and the absence of harmful chemicals, in particular formaldehydes. As alternative upholstery materials, you can use microfiber fabrics, which are characterized by high wear resistance and ease of care at a relatively low price, or eco-leather on a natural basis (for example, with a cotton lining), which provides the visual aesthetics of leather and has a smaller environmental footprint than traditional polyvinyl chloride (PVC) or polyurethane (PU) on a synthetic basis, combining aesthetics with improved resistance to liquids.

The "Sofa-Table" project, which successfully combines an engineering solution for transformation with a well-founded choice of materials, is a multifunctional object that meets modern requirements of ergonomics and sustainable materials science, providing significant space savings.

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НИЗЬКОВУГЛЕЦЕВІ БУДІВЕЛЬНІ МАТЕРІАЛИ ЯК КЛЮЧОВИЙ ЧИННИК ЗЕЛЕНОЇ ТРАНСФОРМАЦІЇ БУДІВЕЛЬНОЇ ГАЛУЗІ

У роботі розглянуті приклади екологічних будівельних матеріалів, які знижують низьковуглецевий слід будівельної галузі, а також фактори, які спонукають до зеленої трансформації будівельної галузі.

Ключові слова: низьковуглецеві будівельні матеріали, оцінка життєвого циклу, ESG-індикатори, CarbonCure Technologies, композити на основі міцелію (Mycelium based composite)

Сучасні будівельні матеріали, окрім високих міцнісних та інших експлуатаційних характеристик, мають відповідати вимогам екологічності та відновлювальності. Важливим аспектом, на який вже звертається увага міжнародних інвесторів та державних органів при наданні фінансування та відповідних дозволів, є так звана оцінка життєвого циклу будівельної продукції (Life Cycle Assessment або LCA) та EGS-критерії підприємства, на якому вона виготовлялася.

Оцінка життєвого циклу будівельної продукції – системний аналіз послідовних та взаємопов'язаних стадій існування будівельної продукції та впливу кожної із них на довкілля. До стадій життєвого циклу будівельної продукції відноситься видобування сировини з природних ресурсів; транспортування/постачання її на завод; підготовка та розробка виробничих процесів; матеріально-технічне забезпечення; виробництво продукції; контроль якості продукції; пакування та зберігання продукції; монтаж або інші технології виробництва, які при цьому використовувалися для зведення будівель із цієї будівельної продукції; ремонт та технічне обслуговування протягом експлуатації будівлі; демонтаж; способи утилізації будівельної продукції після закінчення терміну експлуатації і т.п.

ESG-індикатори – це показники того, наскільки підприємства та компанії притримуються принципів сталого розвитку. Загалом це абревіатура від Environmental (довкілля), Social (соціальна сфера) та Governance (управління).

Індикатор Environmental включає в себе оцінку рівня використання природних ресурсів (енергії, води, корисних копалин тощо) та утворення відходів, в тому числі викидів парникових газів; захисту довкілля; розробки та запровадження низьковуглецевих та екологічних

технологій. Індикатор Social включає в себе аналіз якості роботи компанії з різними людьми: власним персоналом, клієнтами тощо. Індикатор Governance оцінює прозорість та доброчесність роботи компанії, відсутність корупційних складових та наявність чесного внутрішнього аудиту.

Відповідно до нового Регламенту ЄС 2024/3110 Європейського Парламенту та Ради від 27.11.2024, що встановлює гармонізовані умови для розміщення на ринку будівельної продукції та скасовує Регламент (ЄС) № 305/2011 [1], вводяться в обіг обов'язкові цифрові паспорти продукції (Digital Product Passport) та оцінка життєвого циклу продукції. В цифрових паспортах продукції повинні бути вказані дані щодо її експлуатаційних характеристик та впливу на довкілля протягом усього її життєвого циклу.

Таким чином, для можливості збуту будівельної продукції на європейському ринку та отримання інвестицій з-за кордону для реалізації масштабних будівельних проєктів із відновлення країни українські компанії мають враховувати ці європейські вимоги.

В Європі та світі все більше з'являється наукових досліджень присвячених розробці екоматеріалів, які зазвичай модифіковані різноманітними відходами. Найбільше зацікавлення викликають екобетони та екоцементи. Адже, за даними Global Alliance for Buildings and Construction [2], основними забруднювачами в будівельній індустрії є цемент та сталь, на долю яких сумарно припадає 18 % всіх світових викидів парникових газів та основна кількість утворених будівельних відходів.

В роботі [3] вчені розробляють екологічний бетон із переробленого скляного порошку (Waste glass powder або GP) та перероблених заповнювачів таких як перероблений бетонний заповнювач (Recycled concrete aggregate або RCA) та перероблений дрібний цегляний заповнювач (Recycled fine brick aggregate або RFBA) із відпрацьованої глиняної цегли. Waste glass powder використовується як пуцоланова добавка, яка зменшує частку цементу в бетоні, Recycled concrete aggregate – як замітник частки крупного заповнювача, Recycled fine brick aggregate – як замітник частки дрібного заповнювача. Результати досліджень показують, що оптимальним є наступне співвідношення матеріалів: 10 % GP; 15 % RCA; 40 % RFBA; 0,48 водоцементне співвідношення. 28-денна кубічна міцність на стиск зразків бетону такого складу досягала значень у 39,2 МПа, що відповідає вимогам бетону класу С30. Осьова міцність на стиск і міцність на розрив при розколюванні становлять відповідно 29,8 МПа і 2,72 МПа, що також відповідає проектним вимогам до бетону С30. При цьому варто зазначити, що розроблений склад бетону на основі відходів досягає понад 90 % міцності на стиск традиційного бетону на природних заповнювачах. Покращилася і мікроструктура бетону. Утворені завдяки реакції GP і RFBA гелі типу С-(А)-S-H зменшили пористість приблизно на 18 % і збільшили

частку нешкідливих пор розміром <20 нм до 25...28 %. Дослідження виявили щільне заповнення зони міжфазного переходу гелем, при цьому співвідношення Ca/Si гелю зменшилося до 0,29, що сприяло підвищенню міжфазного зчеплення.

Таким чином, розроблений склад бетону на відходах дозволяє знизити на 10 % кількість цементу та приблизно на 50...60 % кількість природних заповнювачів порівняно з традиційним бетоном класу С30. Це сприяє вирішенню одразу кількох проблем: використання невідновлювальних природних ресурсів, екологічне управління відходами та збереження земельних угідь і довкілля загалом.

Ще в 2012 році в Канаді у штаті Нова Шотландія заснована компанія CarbonCure, яка запровадила CarbonCure Technologies, основним принципом якої є зменшення низьковуглецевого сліду бетонів шляхом утилізації вуглекислого газу. Ця технологія передбачає впорскування певної дози CO₂ у свіжий бетон під час перемішування компонентів через спеціальний клапанний блок (рис. 1) [4]. Його дозування контролюється блоком керування, який синхронізований із програмним забезпеченням у диспетчерській, за тим самим принципом що і додавання звичайної добавки. При цьому CO₂ вступає в хімічну реакцію з іонами кальцію, що містяться в цементі, утворюючи карбонат кальцію. Цей процес називається мінералізацією і дозволяє «вбудувати» CO₂ в бетон. В результаті цього вдається значно зменшити витрату цементу при збереженні характеристик бетонної суміші та бетону; підвищити міцність бетону на стиск; зменшити вуглецевий слід на довкілля за рахунок поглинання CO₂ та зниження витрати цементу, що, в свою чергу, дозволить протистояти змінам клімату у світі.



Рисунок 1. Подача вуглекислого газу у бетономішалку [4]

Все більшої популярності набувають натуральні теплоізоляційні матеріали, які називають біоізоляцією. Це екологічні утеплювачі на основі природної сировини (коноплі,

міцелію грибів, овечої шерсті і т.п.), які здатні частково або повністю біорозкладатися. Їх основною перевагою під час експлуатації є те, що вони дозволяють утепленням огорожувальним конструкціям «дихати», регулюючи рівень вологості у приміщенні та перешкоджаючи утворенню цвілі. Особливу увагу, наразі набувають біоізоляційні матеріали із міцелію грибів, які забезпечують ефективну тепло- та звукоізоляцію. Композити на основі міцелію (Mycelium based composite або MBC) утворюються внаслідок вегетативного та/або повітряного росту міцелій грибів на органічних матеріалах, зазвичай сільськогосподарських відходах [5]. Серед найпоширеніших субстратів – агропромислові, лісові залишки та залишкова біомаса первинних і вторинних лісів (зерна пшениці, льняні відходи, пшенична солома, тирса тощо). Ріст грибних міцеліїв залежить від природи субстрату та його обробки, параметрів росту, харчових потреб і генетичних характеристик гриба, який використовується. Як зазначається в роботі [6] композити на основі міцелію мають низьку теплопровідність, високу пористість, низьку щільність, достатньо високий вміст вологи та повітря. Їх теплопровідність залежить від різних факторів, головними з яких є густина композиту, вологість та тип волокна, яке використовується у якості підкладки. Так, міцелієві композити, виготовлені із таких субстратів, як льононі відходи, солома та конопля, мають показники теплопровідності в межах від 0,05 до 0,07 Вт/(м·К), що є подібними до більшості поширених теплоізоляційних матеріалів, таких як скляна вата та екструдована полістирольна ізоляція. При цьому найвищу теплопровідність показав композит із льононих відходів через високе співвідношення ваги до об'єму підкладки, а найнижчу теплопровідність – композит на основі конопель.

Висновок. Отже, використовуючи альтернативні низьковуглецеві матеріали та будівельні технології можна значно зменшити викиди вуглецю, пов'язані з виробництвом традиційних будівельних матеріалів. Тим більше, до зеленої трансформації будівельної галузі та її переходу до низьковуглецевих будівельних матеріалів спонукають регуляторні рамки багатьох країн світу та ринкові умови. Уряди всього світу впроваджують більш суворі норми щодо викидів вуглецевого газу та шкідливого впливу на навколишнє середовище через відповідні екологічні податки та екологічну сертифікацію будівель, таких як LEED та BREEAM, стимулюючи галузь до використання екологічних сталих матеріалів. Необхідні подальші дослідження експлуатаційних характеристик нових будівельних матеріалів та можливості їх широкого виробництва та використання в Україні.

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