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THE IMPACT OF CLIMATE CHANGE ON THE CHOICE OF CONSTRUCTION TECHNOLOGIES

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Abstract

Modern construction is undergoing a profound transformation driven by global climate change. Rising temperatures, increased humidity, extreme precipitation, and wind loads are forcing a rethinking of architectural and engineering approaches and the principles of selecting construction technologies. This article provides a comprehensive analysis of the impact of climatic factors on the design, technological, and operational characteristics of buildings. Particular attention is paid to the adaptation of construction technologies to various climatic zones worldwide, including Europe, the Middle East, Russia, Kazakhstan, and the Caucasus region.

This article examines current trends in the evolution of building materials and architectural solutions, including the use of phase-changing and geopolymer materials, ventilated facades, dynamic envelopes, energy storage systems, and climate-active coatings. The role of digitalization is highlighted, including the implementation of BIM and CFD modeling, artificial intelligence technologies, and predictive microclimate control. Particular emphasis is placed on the integration of renewable energy sources (solar, geothermal, and wind systems) into the structure of buildings and urban developments.

The scientific novelty of this study lies in its rationale for shifting from the concept of sustainable to self-adaptive construction, which views buildings as intelligent systems that interact with the climate and are capable of energy self-regulation. The practical significance of this work lies in the potential application of the identified principles in developing national standards for climate-resilient construction, improving architectural design, and shaping national environmental policy in the construction sector.

Keywords: adaptation, architecture, geopolymer materials, ecology.

Introduction: The current stage of human development is characterized by a rapid intensification of climate processes, affecting all spheres of life—from agriculture to the architectural and construction industries. According to the latest synthesis report of the Intergovernmental Panel on Climate Change (IPCC, 2023), the global surface temperature of the Earth has increased by more than 1.1°C compared to pre-industrial levels, leading to an increase in the frequency of extreme weather events—floods, droughts, hurricanes, and temperature anomalies [11, pp. 45–48]. These processes create fundamentally new challenges for the construction industry, which traditionally relies on long-term climate standards and the stability of materials under specific temperature and humidity conditions [17, pp. 61–64].

Climate change affects not only the performance of buildings but also the very paradigm of design and the choice of construction technologies. As average temperatures rise and precipitation patterns shift, traditional solutions become less reliable: building insulation deteriorates, façade materials degrade faster, and foundation behavior changes as groundwater levels fluctuate. As a result, architects and engineers are forced to find a balance between energy efficiency, environmental friendliness, and resilience to new climate realities [10, pp. 112–115].

Adaptive design technologies that take into account projected climate scenarios are becoming particularly important. According to UNEP research (2022), the main challenge for the construction industry in the coming decades is to reduce the carbon footprint of buildings and adapt design solutions to extreme temperatures and humidity [21, pp. 15–19]. The European Commission takes a similar position in the Energy Performance of Buildings Directive (EPBD), requiring the integration of climate-resilient solutions into architectural planning [7, pp. 4–6]. Thus, the relevance of this topic is determined not only by environmental factors but also by economic, engineering, and regulatory ones.

At the turn of the 21st century, the construction industry is no longer simply a "building manufacturer"—it is becoming a strategic tool for sustainable development. Technological advances (BIM, digital microclimate modeling, "smart materials") enable the design of structures that dynamically interact with the environment, compensating for negative climate impacts [13, pp. 202–206]. In this context, the choice of construction technologies is becoming not a technical but a civilizational challenge, directly linked to energy security, comfort, and the sustainability of the urban environment.

International studies demonstrate that adapting buildings to climate change reduces overall energy consumption by 30–45% and extends the service life of structures by 20–25% [4, pp. 1136–1139; 5, pp. 33–35]. An example of the successful integration of climate approaches is provided by Northern European countries, where the principles of the “passive house” and BREEAM standards have become a mandatory element of urban development policy [3, pp. 57–61]. In contrast, countries in hot regions (the Middle East, South Asia) are developing concepts of cooling facades, windscreens, and passive ventilation systems [1, pp. 102–105]. These contrasts emphasize that architecture is becoming a space of interaction between people, technology, and climate.

In line with global trends, regional research in the post-Soviet space has intensified in recent years. For example, in Kazakhstan, Azerbaijan, and Russia, efforts are underway to find solutions for the implementation of energy-efficient materials, heat-resistant coatings, and heat recovery systems adapted to local climatic anomalies [12, pp. 98–99; 2, pp. 60–62; 15, pp. 141–144]. This experience demonstrates that innovation in construction cannot develop in isolation—it requires consideration of local natural factors, as well as coordination between engineering science, economics, and environmental policy.

Thus, the purpose of this study is to systematically analyze the impact of climate change on the choice of construction technologies, determine factors for adapting design solutions, and identify promising areas for sustainable development in the construction industry. The study's objectives include:

1. generalization of international and regional approaches to climate adaptation of construction technologies;
2. analysis of key innovations in the field of energy-efficient and bioclimatic solutions;
3. identifying areas of scientific and engineering innovation in the design of buildings of the future.

The scientific significance of this topic is determined by the need to develop comprehensive strategies that integrate climatology, architecture, and engineering modeling into a unified knowledge system. The research results contribute to the development of new principles of sustainable design and deepen the understanding of how climate transforms the very logic of technological choice in construction [6, pp. 270–272; 19, pp. 3620–3624].

1. Global climate trends and their impact on the built environment

The current climate situation is characterized by the acceleration of processes previously considered long-term. According to the Intergovernmental Panel on Climate Change (IPCC), the rate of increase in the average global temperature in the 21st century is twice that of the 20th century [11, pp. 48–51]. This is accompanied by an increase in the frequency of anomalies: heat waves in Europe, floods in Asia, and permafrost degradation in the northern regions of Eurasia. Such changes directly impact the operational parameters of buildings, their energy efficiency, durability, and structural stability [8, pp. 111836–111838].

Climate stress on building structures manifests itself through four key factors: temperature, humidity, wind, and solar radiation. Rising average temperatures lead to thermal expansion of materials, causing deformation and premature failure. Rising humidity intensifies corrosion processes, and unstable wind flows increase the demands on the aerodynamic strength of façade systems [20, pp. 72–75].

In countries with continental and sharply continental climates, including Kazakhstan and Russia, so-called "thermal contrast stress" is observed—an alternation of temperature maximums and minimums during the day, which leads to fatigue failure of concrete and metal joints [12, pp. 97–99]. For southern regions (the Middle East, Central Asia), the dominant factor is overheating of the outer building envelopes, which increases energy consumption for air conditioning to 45–55% of total annual energy consumption [1, pp. 102–104].

To better reflect the scale and specificity of climate impacts, it is appropriate to present the summarized data in comparative form:

Table 1.

The influence of the main climatic factors on building structures and technological choices

Climate factor	Manifestation	Impact on buildings	Engineering and technological answer
Temperature increase	Increased thermal load on facades and roofs	Overheating, loss of thermal insulation properties	Application of reflective coatings, heat-resistant materials, ventilated facades [18, pp. 215–217]
Rising humidity	Condensation, biocorrosion	Acceleration of aging of materials, mold, fungus	Use of moisture-resistant concrete, sealed membranes, vapor barriers [10, pp. 115–118]
Strengthening wind currents	Increased aerodynamic loads	Damage to roofs and facades	Aerodynamically optimized designs, strengthening of fastening units [15, pp. 196–198]
Increased solar radiation	Increase in heat input	Overheating of premises, increased energy consumption	Sun protection facades, photochromic glass, intelligent blinds [3, pp. 63–65]

As the table shows, each climate impact transforms into an engineering challenge requiring new materials and design solutions. A clear pattern emerges: the greater the region's climate instability, the more complex the technological choices. In countries with moderate climates, the emphasis is on reducing energy consumption, while in hot zones, thermal protection and cooling become a priority [5, pp. 31–34; 9, pp. 22–23].

It's significant that the global construction industry is already adapting to these challenges. For example, in the European Union, a directive has been in effect since 2021 requiring all new buildings to comply with the Nearly Zero Energy Building (NZEB) standard [7, pp. 6–8]. These standards require that a building's energy needs be minimal, with thermal balance achieved through passive ventilation systems and solar energy generation. In Scandinavia, similar principles are being implemented in "passive house" architecture, which achieves a 90% reduction in heat loss thanks to airtight envelopes and heat recovery [13, pp. 204–206].

At the same time, in countries with high solar activity (UAE, Qatar, Saudi Arabia), an opposing concept—"smart cooling" architecture—is developing. Here, façade systems with reflective coatings, passive wind towers, and bioclimatic ventilation regulation are being implemented [1, pp. 103–106]. These practices demonstrate that climate adaptation has no universal model: it is always region-specific, and it is precisely this flexibility that is becoming a hallmark of modern technological thinking.

The impact of climate fluctuations on the operating costs of buildings deserves special attention. According to researchers Bribián and Usón, the share of the carbon footprint associated with the operation of structures reaches 60–70% of the total life cycle of a building [4, pp. 1136–1139]. The introduction of adaptive technologies (dynamic facades, intelligent microclimate sensors, phase-change materials) makes it possible to reduce these indicators by almost half, confirming the direct relationship between climate resilience and economic efficiency [6, pp. 270–272; 19, pp. 3622–3623].

Taken together, the data reviewed allows us to conclude that the modern construction industry is transitioning from a static to a climate-responsive design model. The key change lies not only in the use of new materials but also in a restructuring of engineering thinking—from local adaptation to integrated sustainable development strategies.

2. Evolution of construction technologies under the influence of climate challenges

The transition from traditional construction methods to climate-responsive design technologies is one of the most significant transformations in the history of construction science. While the 20th century was defined by functionalism and industrialization, the 21st century is characterized by a shift to ecological engineering thinking, where buildings are perceived not as static objects but as dynamic systems interacting with climate and energy flows [16, pp. 23–27].

This evolution is driven not only by environmental awareness but also by objective engineering factors. According to Kibert (2022), more than 40% of global energy consumption and approximately 30% of carbon dioxide emissions are associated with the construction and operation of buildings [13, pp. 118–120]. In response to these challenges, architecture is beginning to integrate principles of energy efficiency and closed-loop material life cycle assessment (LCA), which allows for the optimization of the energy and carbon balance of structures [4, pp. 1134–1137].

New generation materials and technological modernization

One of the key areas of this evolution has been the introduction of new-generation materials that combine energy efficiency, environmental friendliness, and climate resistance. Leading researchers in the field of sustainable construction (Pacheco-Torgal, Labrincha, 2014) note the growing popularity of nanostructured concrete, heat-reflective paints, and composite panels with variable thermal conductivity [18, pp. 101–104]. These materials are capable of adapting their properties depending on temperature, humidity, and solar radiation, thereby reducing the load on heating and cooling systems.

Particular attention is being paid to "smart materials" technologies—substances that exhibit a reversible response to external climatic stimuli. For example, phase-changing materials (PCMs) accumulate excess heat during the day and release it at night, stabilizing the internal microclimate [17, pp. 174–178]. The use of such solutions allows for energy consumption reductions of up to 25–30% without significantly increasing capital expenditures [6, pp. 270–272].

Another trend is the development of ventilated facades and "breathing" envelopes. These systems allow buildings to "respond" to temperature changes, providing natural air exchange and preventing condensation [10, pp. 118–121]. This increases the durability of structures, reduces the risk of biocorrosion, and lowers operating costs.

Energy-efficient design and digital technologies

Along with the development of materials, the logic of architectural design has also changed. Energy modeling and digital microclimate forecasting have taken a leading position. Modern BIM (Building Information Modeling) technologies allow for the simulation of heat flows, solar insolation, and wind loads during the design stage [14, pp. 6655–6657]. This makes it possible to accurately determine the optimal building orientation, insulation thickness, and window configuration, which is especially important when designing for a changing climate.

CFD (Computational Fluid Dynamics) systems simulate the behavior of air and moisture around and within a building, preventing façade overheating, increasing ventilation efficiency, and reducing aerodynamic risks [8, pp. 111837–111838]. Thus, digitalization is becoming an integral element of climate-resilient construction.

Bioclimatic architecture and integration of renewable energy sources

Bioclimatic architecture, based on the harmony between the building and its surroundings, plays a significant role in the development of adaptive technologies. The concept of bioclimatic design was formulated by Viktor Olgiay in the mid-20th century, but in recent decades it has been further developed thanks to digital technologies [16, pp. 54–58]. Key principles include the rational use of cardinal orientation, consideration of local wind patterns, and the integration of green spaces to create natural ventilation and cooling.

The Nearly Zero Energy Building (NZEB) concept combines bioclimatic architecture with renewable energy sources—solar panels, wind turbines, and heat pumps [17, pp. 223–225]. These technologies provide the building with autonomy and compensate for fluctuations in climate parameters, creating a sustainable energy balance. In Northern European countries, such systems have already become the design norm, while in Central Asia and the Caucasus region they are only just beginning to be implemented [2, pp. 61–63; 12, pp. 99–101].

Transformation of design solutions and architectural form

An equally significant component is the change in architectural form itself. Under the influence of climatic factors, buildings are becoming more aerodynamically stable—with smooth façade lines, reduced overhangs, and reduced resistance to wind flow [15, pp. 197–199]. In areas with increased insolation (for example, the Middle East), façades with dynamic panels that respond to the intensity of sunlight are gaining popularity [1, pp. 104–106].

A new type of structure is emerging—adaptive envelopes—that can change their properties in real time in response to weather conditions. The use of photochromic and temperature-sensitive materials allows for the regulation of light transmission and thermal balance without human intervention [3, pp. 62–64; 19, pp. 3621–3623]. These solutions represent a synthesis of architecture and artificial intelligence technologies, forming the basis of a smart, climate-self-regulating building.

Engineering and scientific innovation

Modern research shows that the further evolution of building technologies is aimed at creating intelligent climate control systems, where the building's interaction with the climate becomes algorithmically controlled. Unlike the passive systems of the past, new solutions utilize sensor networks and software-based microclimate control, making it possible to develop a "building data life cycle" (BDLC) [14, pp. 6656–6658].

The scientific novelty of this approach lies in the shift from the principle of sustainability to the principle of self-adaptation. While sustainability implies resistance to external influences, self-adaptation is a building's ability to predictively change its parameters in response to predicted climate scenarios. Thus, the building of the future becomes not simply an object of operation but a participant in energy and climate exchange, shaping a new engineering philosophy for the 21st century [6, pp. 270–273].

3. Regional approaches to the adaptation of construction technologies

The evolution of climate-resilient construction demonstrates not only general global trends but also regional differences reflecting the specifics of natural conditions, economic opportunities, and regulatory systems. The impact of climate on architectural and construction practices varies across the globe: in northern countries, the priority is heat conservation, while in southern countries, it is protection from overheating and ventilation [8, pp. 111835–111837]. This differentiation shapes the diversity of technological solutions and regional models of sustainable construction.

3.1. Europe and North America: Standardization of Sustainable Construction

In the European and North American contexts, climate adaptation has long since reached the level of state strategies. The basis for these approaches is the international standards LEED, BREEAM, and WELL Building, which set criteria for energy efficiency, water conservation, waste management, and indoor climate quality [22, pp. 124–128; 3, pp. 59–61]. In accordance with the Energy Performance of Buildings Directive (EPBD, 2018/844/EU), all new buildings in the European Union must have near-zero energy consumption from 2021 [7, pp. 5–6].

Nordic countries are characterized by an emphasis on heat conservation and carbon footprint reduction. Finland, Sweden, and Norway actively utilize heat recovery systems, triple-glazed windows, super-insulated panels, and low-U-value facades [13, pp. 221–223]. Passive house architecture has become a widespread phenomenon: according to estimates by the European Council on Energy Efficiency, it reduces energy loss by

90% compared to traditional buildings [17, pp. 229–231].

In North America, the development of adaptive technologies relies on private investment and technological innovation. Building information modeling (BIM) and digital twins of buildings are common here, enabling microclimate monitoring and predicting heating and cooling loads [14, pp. 6657–6658]. An example is the Bullitt Center project in Seattle, which is entirely self-sufficient in energy through solar panels and rainwater recycling systems [6, pp. 271–272]. Thus, climate adaptation in Western countries is closely linked to digitalization and regulation.

3.2. Asia and the Middle East: Combating Overheating and Water Scarcity

In the hot, dry climates of the Middle East and South Asia, reducing overheating and rational water use are priorities. Architectural adaptation in these regions relies on the principles of bioclimatic design, which combine ancient traditions with modern engineering solutions [1, pp. 103–106]. For example, in the UAE, facades with automatic sun protection panels are widely used, while in Saudi Arabia, natural ventilation systems through vertical shafts, reminiscent of traditional "wind towers" (badgir) [18, pp. 311–313].

According to Al-Saadi (2021), the implementation of passive cooling systems and dynamic façades can reduce buildings' air conditioning energy costs by 35–50% [1, pp. 104–105]. In Qatar, the Msheireb Downtown Doha project has been implemented—the world's first "smart" city built entirely according to climate integration principles. The complex's architecture takes into account wind direction, solar activity, and humidity, providing natural cooling and reducing carbon emissions [19, pp. 3622–3624].

It should be noted that Asian countries, particularly China and India, are rapidly developing water conservation and condensate reuse systems, which are becoming part of the "zero water footprint" strategy (Zero Water Building). These solutions are particularly relevant for regions experiencing increasing drought and freshwater shortages [21, pp. 17–18].

3.3. Russia and the CIS countries: adaptation to a continental climate

In post-Soviet countries, climate conditions require a universal approach: heat retention in winter and protection from overheating in summer. This is characterized by wide temperature fluctuations and uneven precipitation. Therefore, the primary focus is on heat-saving structures and climate-friendly materials.

Modern research by Russian and Kazakh scientists shows that the most effective approach is the use of multilayer thermal panels with dynamic properties that allow for the regulation of heat transfer [10, pp. 122–125]. At the same time, the production of moisture-resistant concrete and geopolymer mixtures resistant to freeze-thaw cycles is developing [9, pp. 23–24; 15, pp. 201–203].

In Kazakhstan and Central Asia, interest in combined heating systems based on solar collectors and heat pumps is growing. According to Kalmatsky and Kurbatova (2020), such solutions reduce energy consumption by up to 40% and stabilize the microclimate in conditions of sudden temperature fluctuations [12, pp. 99–100]. Similar experiments are being conducted in Azerbaijan, where traditional architectural forms (high ceilings, shade-forming elements) are combined with modern thermal insulation and air recovery technologies [2, pp. 60–62].

3.4. Comparative characteristics of regional adaptation models

For a more visual comparison of the approaches of different regions, a summary table is presented:

Table 2.

Regional strategies for climate adaptation of building technologies

Region	Climate challenges	Technological solutions	Key standards and practices
Europe, North America	Cooling, energy efficiency	Passive houses, triple-glazed windows, heat recovery, BIM modeling	LEED, BREEAM, EPBD [3; 7; 22]
Asia, Middle East	Overheating, lack of water	Wind towers, solar screens, dynamic facades, water conservation	Zero Water Building, Green Building Code [1; 18; 21]
Russia, CIS	Continental climate, temperature fluctuations	Multilayer panels, geopolymer concrete, combined heating	GOST R 54964–2012, energy efficiency standards of the CIS [9; 10; 12]

Overall, regional strategies demonstrate that adapting construction technologies to climate change is impossible without considering local natural and socioeconomic contexts. While universal standards focused on carbon neutrality prevail in Europe, Asian and CIS countries are developing hybrid models that combine traditional construction principles with innovative microclimate control systems.

Thus, the regionalization of climate-resilient construction serves as a basis for global technological diversification, opening up opportunities for the creation of national standards for “smart” construction that take into account historical traditions, local materials and natural features [2, pp. 61–63; 15, pp. 202–204].

4. Promising areas of development

The modern construction industry is undergoing a period of conceptual restructuring, driven by a shift from the principle of sustainability to the principle of adaptability. While the engineer's task previously was to ensure the strength and energy efficiency of a structure, today the primary focus is on creating self-regulating architectural systems capable of dynamically responding to climate change. These trends are shaping a new technological paradigm—intelligent climate design, which integrates digital modeling, smart materials, and controllable energy systems [6, pp. 270–273].

4.1. Digital modeling and predictive microclimate control

One of the key development areas is the implementation of digital technologies in building lifecycle management. Modern BIM (Building Information Modeling) and CFD (Computational Fluid Dynamics) analysis systems are no longer limited to 3D design—they are becoming tools for predictive climate analytics. They can be used to simulate air flow behavior, temperature fields, solar radiation dynamics, and humidity in real time [14, pp. 6655–6657].

New algorithms based on artificial intelligence allow buildings to "learn" and adapt their energy consumption to changing climate conditions. For example, the Smart Adaptive Building project in Germany has implemented a system that automatically adjusts ventilation, lighting, and heating based on the outside temperature and weather forecast [17, pp. 233–235]. These solutions form the basis of the Building Data Life Cycle concept, in which climate information becomes a constant element of a building's operational cycle [13, pp. 208–210].

The implementation of digital modeling helps reduce building operating costs by up to 30%, as well as carbon emissions by 20–25% due to optimized heat exchange and ventilation [19, pp. 3623–3624]. Thus, digitalization not only increases the resilience of building systems but also enables a transition to predictive design, where climate risks are anticipated and mitigated before construction begins.

4.2. Smart and self-adapting materials

The second direction is the development of smart materials capable of changing their physical and chemical properties in response to external climatic stimuli. According to research by Pacheco-Torgal and Cabeza (2013), the use of phase-changing materials (PCMs), photochromic glass, and temperature-sensitive coatings makes it possible to create building envelopes that "regulate" temperature without mechanical intervention [17, pp. 179–181].

Bioinspired materials that mimic natural thermoregulatory mechanisms—for example, microcellular structures that replicate the structure of plant leaves—are particularly promising. Such materials are used in façade systems, where they reflect excess solar radiation and retain moisture at high temperatures [18, pp. 108–110].

Furthermore, geopolymer concretes with a low carbon footprint are actively developing, in which cement is completely or partially replaced with fly ash and metakaolin. These materials are not only stronger than traditional cement but also reduce CO_2 emissions by 40–60% [10, pp. 125–128].

In terms of scientific innovation, the use of smart materials allows us to discuss the development of a new class of functionally active building envelopes that not only insulate but also regulate the building's interaction with the environment. This approach radically changes the understanding of the function of a wall or façade: they are transformed from passive barriers into active elements of the building's climate system [4, pp. 1137–1138].

4.3. Integration of renewable energy sources

The next development vector is the increased integration of renewable energy sources (RES) into building structures. The Net Zero Energy Building (NZEB) concept is already being implemented in the EU, the US, and Asia, where buildings are capable of producing as much energy as they consume through solar panels, wind turbines, and heat pumps [7, pp. 6–8; 22, pp. 125–127].

Modern developments are aimed at creating integrated energy envelopes in which solar cells are integrated directly into façade panels. These solutions not only reduce the cost of installing photovoltaic systems but also enhance the aesthetic expression of architecture [3, pp. 63–65]. According to UNEP (2022), by 2040, energy-saving buildings could account for up to 35% of the global building stock [21, pp. 20–21].

Hybrid systems combining solar and geothermal energy are particularly relevant for the CIS and Central Asian regions. Such solutions compensate for seasonal temperature fluctuations and ensure year-round energy stability [12, pp. 99–101; 2, pp. 60–61].

4.4 The role of public policy and regulation

Without systemic government support, the transition to climate-smart construction is impossible. EU experience shows that the implementation of green technologies is stimulated not only through standards (BREEAM, LEED, EPBD), but also through tax incentives and subsidies [7, pp. 7–9]. In Russia and the CIS, similar initiatives are the "Energy-Efficient Home" programs and regulatory documents—GOST R 54964–2012, which regulate environmental requirements for real estate [9, pp. 24–25].

In Azerbaijan and Kazakhstan, national sustainable design standards are being developed, focusing on the combination of traditional architectural forms and modern engineering solutions [12, pp. 100–102; 2, pp. 61–62]. However, as comparative studies show, the main barrier remains insufficient digitalization and the high cost of energy-efficient technologies [15, pp. 203–205].

The future development of climate-responsive construction requires the creation of integrated regulatory systems that integrate requirements for energy efficiency, carbon neutrality, and sustainability. This will harmonize approaches across the CIS and integrate national standards into international sustainable development initiatives.

Thus, an analysis of promising trends allows us to conclude that the construction industry of the future will be defined not so much by architecture as by its ability to self-learn and interact with the climate. The scientific novelty of this trend lies in the formation of a synthetic design model in which digital analytics, smart materials, and renewable energy form a single technological organism that responds to environmental dynamics [6, pp. 272–273; 18, pp. 109–111].

Conclusion

The modern architectural and construction industry is entering an era where climate ceases to be an external design constraint and becomes an internal parameter. Climate change is not simply an environmental issue, but a factor in technological transformation that determines the development of engineering thought, architectural form, and building materials. The results of the analysis showed that sustainable construction is impossible without a shift from traditional functionalism to an adaptive and intelligent design model in which the building interacts with the environment as an active participant in climate exchange [6, pp. 270–273].

A systematization of global experience has demonstrated that climate challenges in different regions are addressed through various technological strategies: from energy-efficient and passive houses in Europe to innovative cooling facades in the Middle East and thermal stabilizing panels in the CIS countries [1, pp. 104–106; 12, pp. 99–101; 22, pp. 125–127]. A unifying element across all these approaches is a focus on energy efficiency, durability, and digital control of buildings.

Digital modeling technologies, smart materials, and the integration of renewable energy sources are acquiring particular importance. These solutions form the core of a new engineering philosophy, in which the concept of "sustainability" is transformed into the category of self-adaptation—the ability of a building to predict and compensate for climate change. This is a qualitatively new level of development in building systems, ensuring not only economic and environmental efficiency but also increased human comfort [14, pp. 6656–6658; 17, pp. 233–235].

Regional examples confirm that there is no universal recipe for climate adaptation. On the contrary, it is precisely the localization of solutions that becomes a sign of the maturity of architectural culture. This is the key scientific conclusion: sustainable construction in the 21st century is not a global template, but a flexible matrix that integrates international standards and local natural and cultural characteristics [2, pp. 61–62; 10, pp. 122–125].

Thus, the impact of climate change on the choice of construction technologies is manifested in three interconnected planes:

1. **Material and technological**— development of new materials that respond to climate stimuli;
2. **Digital engineering**— implementation of predictive models for microclimate design and management;
3. **Normative and strategic**— development of sustainable construction policies and national environmental design standards.

It is the synthesis of these approaches that forms the foundation of the future architectural and engineering paradigm. In this context, a building ceases to be a passive object—it becomes an intelligent system capable of interacting with the climate, accumulating data, optimizing energy consumption, and minimizing its carbon footprint.

In conclusion, it can be argued that the future of construction is a symbiosis of humans, technology, and nature, where architecture acts as an instrument for ecological balance. Implementing this model requires not only engineering innovations but also a profound cultural rethinking of the role of architecture in the era of climate transformation. And the extent to which the construction industry can integrate these approaches in a timely and systematic manner will determine whether the 21st century becomes an era of climate crisis—or a time for overcoming it through science, technology, and intelligent design [21, pp. 20–21; 13, pp. 208–210].

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