Civil Engineering and Architecture 12(5): 3391-3401, 2024 http://www.hrpub.org
DOI: 10.13189/cea.2024.120519

Innovative Engineering Solutions in Modern Kazakh Architecture: Adapting to Seismic and Climatic Risks

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Received April 23, 2024; Revised July 3, 2024; Accepted Jul 29, 2024

Cite This Paper in the Following Citation Styles

(a): *[1] Yuliya Onichshenko, Gulnara Abdrassilova , "Innovative Engineering Solutions in Modern Kazakh Architecture: Adapting to Seismic and Climatic Risks," Civil Engineering and Architecture, Vol. 12, No. 5, pp. 3391 - 3401, 2024. DOI: 10.13189/cea.2024.120519.*

(b): *Yuliya Onichshenko, Gulnara Abdrassilova (2024). Innovative Engineering Solutions in Modern Kazakh Architecture: Adapting to Seismic and Climatic Risks. Civil Engineering and Architecture, 12(5), 3391 - 3401. DOI: 10.13189/cea.2024.120519.*

Abstract The incorporation of seismic and climatic considerations into the modern architecture of Kazakhstan is crucial and pertinent for achieving a harmonious and environmentally sustainable development of the region. The objective of this study is to validate the distinctive engineering strategies required for the construction of large-scale architectural structures while considering the natural and climatic hazards specific to Kazakhstan. During the scientific research, the following general scientific methods were used: system analysis and synthesis, historical method, and abstract-logical method. In particular, in the course of the conducted research, the history of the development of modern seismic technologies in Kazakhstan was analysed, which began in 1977, when the country's first high-rise building - the 26-story Kazakhstan hotel - was built in Almaty. The unique features of the structural and technical adjustments made to the architectural buildings in the major cities of Kazakhstan, namely Astana and Almaty, in response to the natural and climatic circumstances of the nation, were justified. The general concept of architectural solutions in the construction industry of Kazakhstan and the justification of individual changes in connection with the trends and possibilities of scientific and technical progress in the context of preservation of cultural heritage were characterized. The results of a survey of 300 respondents (mainly engineers and architects) were analysed in order to identify the role of engineering solutions in architecture, determined by the seismic and temperature conditions of Kazakhstan. The practical significance of this study is a detailed analysis of the innovativeness of engineering solutions, considering the example of the buildings of the Republic of Kazakhstan (hotel "Kazakhstan", shopping centre "Khan-Shatyr", "Palace of Peace and Harmony", multifunctional complex "Talan Towers"). These results can be used to substantiate decisions on overcoming complex climatic factors and forming unique images in terms of the new identity of the country's modern architecture.

Keywords Architecture Adaptability of Kazakhstan, Architectural Stability, Natural Risks, Multi-Year Weather Pattern, Balanced Construction, Cultural Innovations, Regional Features of Territorial Planning

1. Introduction

After the collapse of the Union of Soviet Socialist Republics, 15 former Soviet republics began counting down their own post-Soviet history. Among these new states was Kazakhstan. Since 1991, it has introduced many economic, social, political, scientific and cultural innovations that have created the image of a rapidly developing country. This international image was formed mainly due to the intensive development of its construction industry and architecture. For these years, the city of Astana, which now serves as the capital of Kazakhstan, was constructed. The residential and civil construction sector is experiencing tremendous growth nationwide, with projects by renowned architects and businesses being executed in cities around Kazakhstan. The Republic of Kazakhstan is located in a seismically active area, and there is a risk of large earthquakes. Taking into account this factor in the design and construction of structures becomes a key task to ensure the safety of the population and historical and cultural heritage.

The relevance of this research lies in the fact that providing a comfortable and safe urban environment requires an integrated approach that takes into account various aspects of infrastructure, design and city management. Adaptation to climate change is a key aspect of modern architecture. Developing engineering solutions that ensure the resilience of buildings and infrastructure in the face of risk is critical to protecting life and property. Modern technologies and engineering solutions can significantly improve the quality of construction and ensure balanced development in accordance with modern challenges. The problems of adapting the existing buildings to new conditions and modernising the spatial environment arise for various reasons and require a complex approach for an effective solution. Outdated communication systems, energy networks and other engineering solutions need updating and modernization. The use of inappropriate or dangerous materials in existing buildings creates risks in the field of preservation of natural ecosystems. Most of the buildings that were built 20-30 years ago do not fully reflect the needs of different population groups or people with disabilities.

The problems of low energy efficiency in old buildings were considered in the research conducted by K. Murzabayeva et al. [1]. According to the authors, such a modern negative trend leads to high energy costs for heating and thermoregulation in general. In the study of the field of non-destructive testing and design tools, it was found that the renovation and modernization of old buildings may involve the application of modern methods of thermal imaging, acoustic research, and vibration analysis. The use of computer modeling and modern design software can help understand the impact of various reconstruction options on the energy efficiency of the building and ensure optimal resource utilization during design and construction. Taking into account local climatic conditions to optimise thermal and light comfort is extremely important during nature-oriented landscaping, preservation and restoration of local flora and fauna, and the use of vegetation to reduce the thermal effect of islands and improve the urban climate, which is emphasized in their research by E. Baitenov and G. Issabayev [2]. To stimulate an active lifestyle, it is important to develop parks and recreation areas. The relationship between modern architecture and historical heritage is determined by many factors and can manifest itself in different forms and manifestations depending on the specific context and creative approach. Modern architects can use elements of historical architecture, rethinking them and adapting them to modern needs and technologies, as noted by G. Abdrasilova et al. [3]. The authors noted that there is a growing recognition in the field of non-destructive testing and design tools of the importance of preserving historic structures while implementing modern advances. Technologies such as ground penetrating radar, laser scanning, and photogrammetry are increasingly being used to assess the structural integrity of historic buildings without causing damage.

G. Abdrassilova and E. Danibekova [4] investigated the transformation of the understanding of regional identity in their works, which is an important aspect of the evolution of the architectural environment. Researchers have recognized the significance of understanding and preserving the unique architectural styles and materials indigenous to different regions. Non-destructive testing methods, such as infrared thermography and ultrasonic testing, are being employed to assess the condition of regional architectural elements without causing harm. By utilizing these techniques, architects and preservationists can ensure the longevity and authenticity of regional architectural heritage while incorporating modern advancements in design and construction. The problem of reconciling changes in society, technology, ecology, and cultural trends was considered by H. Truspekova and D. Sharipova [5]. Authors in terms of their impact on how architects perceive and embody regional identity in their projects. The researchers explored innovative approaches to preserving and strengthening regional identity in the face of these dynamic changes. The authors determined that by integrating traditional building techniques with advanced technologies and sustainable design principles, architects can create spaces that reflect the essence of regional identity while meeting the needs of modern society. Modern design tools, such as building information modeling (BIM) and parametric design software, allow architects to visualize and analyze the complex relationship between cultural heritage, environmental considerations, and technological innovation.

The architecture of modern residential and public buildings in Kazakhstan, especially high-rise buildings according to G. Abdrassilova et al. [6] reflects modern trends in design and is characterized by a combination of modernity taking into account local cultural and aesthetic features. Large cities such as Almaty and Astana have tall buildings that are a symbol of economic development and progress [7].

However, the problem of innovative design solutions in architecture, which ensure the resistance of buildings in local climatic conditions and contribute to the creation of unique artistic images of buildings, contains a number of issues that have not fully explored. These aspects are considered the problems of integrating modern technologies into the design of buildings, taking into account socio-cultural development and user needs, and adapting modern architectural planning solutions to the natural and climatic conditions of the region. The objective of this research is to analyse engineering options for unique structures in Kazakhstan, taking into consideration temperature fluctuations and the risk of earthquakes.

2. Materials and Methods

The research information base has collected data from the official Internet project "Qazaqstan Tarihy" under the information committee of the Ministry of Information and Social Development of the Republic of Kazakhstan. This project focuses on the historical formation of Kazakhstan and aims to educate the population about its history. In order to analyse the modern typology of architecture, the data of the Kazakhstan real estate portal Kn.kz were studied, as well as the materials of the periodical publication “Real Estate”, which is one of the leaders among advertising and informational publications covering the housing market, as well as commercial real estate, construction, works, and business.

Analysed using the approach of system analysis and synthesis, the study focused on the structural and technical adaption elements of architectural structures in the main cities of Kazakhstan, namely Astana with a population of 1.3 million inhabitants, and Almaty with a population of 2.2 million inhabitants, in relation to natural and climatic circumstances. The article characterised the basic concept of architectural solutions in the construction sector of Kazakhstan and the rationale behind specific modifications about the trends and possibilities of scientific and technical progress, all within the context of preserving cultural heritage.

The survey of 300 respondents (mainly engineers and architects) was conducted with the help of questionnaire in the period from December 2022 to February 2023. The participants of the sociological survey differed in age and social status, but the main similarity was belonging to the educational and scientific sphere, in particular architecture and construction. The respondents were: students, master’s students, doctoral students, practicing architects, civil engineers, scientists and/or teachers from higher educational institutions. During the survey, groups of factors were determined, which, according to the respondents, have a decisive influence on the choice of engineering solutions in architecture, adapted to modern natural and climatic conditions. The content of the questionnaire reflected the attitude of the respondents to the main factors of the adaptability of architecture in Kazakhstan.

By using the historical approach, the progression of contemporary seismic technology in Kazakhstan was delineated. The initial phase commenced in 1977, coinciding with the construction of the 26-story Kazakhstan hotel in Almaty. The abstract-logical method was used to clarify the fundamental concepts, definitions, and categories in the field of architectural composition of the most significant and prominent towns in the Republic of Kazakhstan. The elements of socio-economic development of urban architecture in the context of modern innovative and traditional approaches to construction were substantiated.

3. Results

The specifics of architecture are conditioned by the geographical location of the region, natural and climatic conditions, construction practices and structures. The strongly continental climate and threat of destructive earthquakes in Kazakhstan have significantly affected the engineering solutions. For example, Almaty, the largest city, is located in a foothill zone of high seismicity. And Astana, the main city in the country, is one of the capitals in the world with the most contrasting climate: with the air temperatures dropping to -40 ℃ in winter, – rising up to +35 ℃ in summer (therefore, overheating the buildings is also actual) [8; 9].

The main districts in Almaty are located on 7 faults of tectonic plates. According to the forecast data, in case of catastrophic earthquakes of grade 9 or higher, up to 30% of residential buildings built before the 1970s may collapse (frame-reed two-story houses with wooden frame, three-four-story brick houses with reinforced concrete floors). Buildings built of glass and metal in the foothills of Almaty are also dangerous. Due to the need for constant monitoring of the seismic situation, the Institute of Earthquake Engineering was established in Almaty, and it is implementing unique experimental studies [10].

The history of modern earthquake engineering in Kazakhstan began in 1977, when the first high-rise building in the country was built in Almaty that was 26-storeyed Kazakhstan Hotel (Figure 1). No buildings higher than 12 floors had been built before in Almaty for fear of the high seismic activity, remembering several destructive earthquakes in the history of the city.

Figure 1. Kazakhstan Hotel for 973 places in Almaty (KazgorStroyProject: architects – Yu. Ratushny, L. Ukhobotov; chief designer – I. Matviets). General view

The building of Kazakhstan Hotel, ellipsoid in plan, has become a distinctive dominant contrasting with the surrounding buildings and accentuating the city centre (Figure 2). The building's light and airy vertical bow window row is completed with a tall attic shaped like a golden, anodized aluminium crown [11]. The hotel's shape and level of comfort were chosen by taking into consideration several design elements, including the direction of the wind and the angle of the sun.

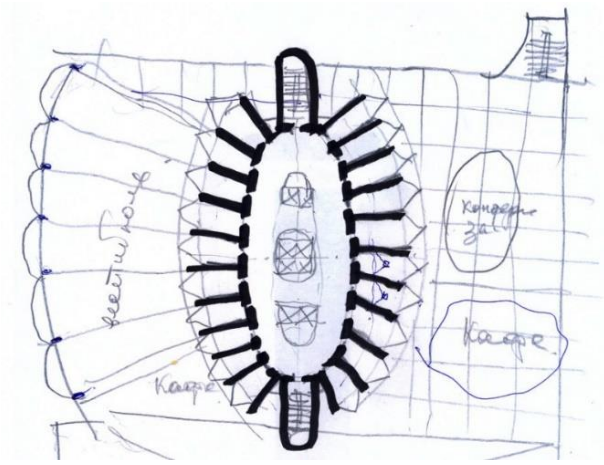

Figure 2. Kazakhstan Hotel Plan. Drawing by architect A. Anchugov

Building materials (aluminium panels, shell rock) which were modern at that time, were used in the exterior decoration. Light panels, where the aluminium sheets were installed, were used on the main and rear facades. An insulation layer was laid between the panels. Plastic panels laid out in a zigzag pattern gave the building a nice, light shape. Light pink Kazakh shell stone was used to line the side façade [3]. Expensive building materials such as marble, aluminium, and synthetic materials were used in the interior. The vast lobby ceiling was decorated with aluminium structures identical to the “crown” on the roof. Labradorite, a black gabbro, lined the floor.

Every floor had a different wall hue. The interior design of the first high-rise building in Kazakhstan, which was modelled after the Baikonur Space Port in the country's south, incorporated a space theme that ran throughout the building. It began in the ground-floor entrance lobby and ended at the top-floor Cosmos restaurant, located at an elevation of 86.1 meters, from which an overlook offers a breathtaking view of the surrounding mountains of Almaty [3]. Using sliding formwork to create a reinforced concrete monolith was a novel approach to building at the time. At the time, Japan was actively making use of it. An oval stiffening core serves as the hotel's primary structural component. The utilities and lift shafts are found in the centre. The walls of the chambers, called diaphragms, stretch away from the oval framework [12]. Anti-seismic stability testing was done shortly before the hotel's construction was finished in 1977. Special sensors on the floors recorded the shocks, and machines that mimicked vibrations were erected at the top of the structure. The structure remained intact during the test. A notable example of engineering art is the Kazakhstan Hotel. It was also Kazakhstan's only skyscraper up until the 2000s. Because the hotel has demonstrated the structure's dependability and structural integrity, it remains a desirable service item [13].

Construction of Astana, the new capital of Kazakhstan, began in 1997, when the government agencies moved here from Almaty, the old capital. The main disadvantage of the former capital such as high seismicity has been replaced by new challenges such as a contrasting temperature regime during the warm and cold periods of the year. The architecture of Astana became part of a political project that aimed at presenting the image of the young capital of the independent state at the international level: world-class architects were invited to Kazakhstan to accomplish this task [14]. Rapid temperature changes in Astana were considered when developing the unique structure of the building of Khan-Shatyr Shopping and Entertainment Centre designed by Norman Foster, a British architect (Figure 3). The idea was to build a building with a year-round tropical microclimate and to adapt it to the harsh weather conditions of the region.

Figure 3. Khan Shatyr Shopping and Entertainment Centre, 2006-2010. Foster + Partners Architectural Bureau, main facade

The facility shape was created by an ethylene-tetrafluoroethylene (ETFE) tent structure, which was covered with hundreds of thousands of silver dots of sun-protection shading in its upper part. The design uses the natural process of flue effect: in windy weather the heated air rises and is drawn out through the holes along the circumference of the top of the tent, above the ring, along the adjustable strips of board. Instead of the air utilized through the top of the tent, fresh, cool air is sucked in from the air intakes near the ground [15].

Thus, the usable area of the Entertainment Centre is air-conditioned and a comfortable temperature is maintained at any time of the year. The building has a lot of natural light due to the high-light transmission of the ETFE material. Excessive heat in the “tropical zone” with swimming pools in winter is used to heat the underground parking up to +5°C. The solution for closing a large space with a dome stated a question of adapting the structures to the project concept. The pressure of such a large-scale dome on the supporting pillars suggested using massive and heavy supporting structures for the building since the construction materials and building elements had to be delivered through territories of several countries, it was important to minimize the weight of the structures. The engineers decided to use the principles of the suspension bridges, where the lightest possible cables carried the weight being in tension. The principle of the tent structure tension made it possible to distribute the forces in the material effectively and reduced steel spread by five times.

The first stage of construction included laying the foundation. It took 188 thousand tons of concrete for the foundation and lower floors of the Centre with a total area of more than 100 thousand m^2. The concrete piles were laid down to a depth of 10 floors. The second stage of construction was implemented after the concrete was poured: a steel structure weighing 2000 tons was installed. The specialists invited by N. Foster made great efforts to solve the problems of erecting the central structure. The central column, which was originally designed by the developers as a vertical column, changed its shape (became inclined) for a number of reasons: the symmetrical shape of the column in the central part was cumbersome and did not provide the required stability. “Khan Shatyr” is the final object of the central axis, along which all the main buildings of the city are aligned – the tent tilt at 15 ℃ was required to avoid breaking this axis [16].

A tripod shape was chosen for the central structure to ensure the structural competence. It was decided to assemble the tripod structure, made in Turkey, on the ground instead of building it vertically in sections (Figure 4).

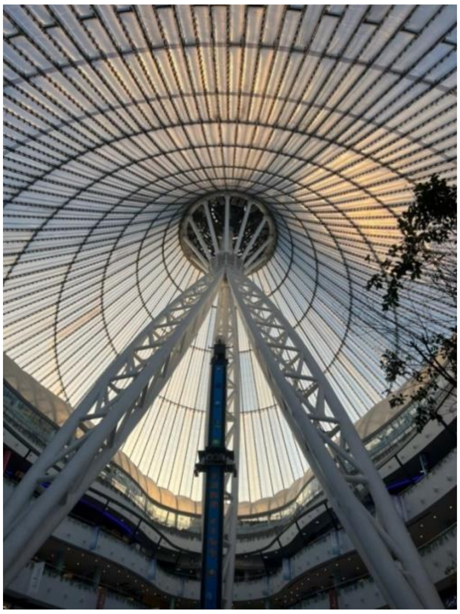

Figure 4. Tripod structure

The third stage of construction included the installation of a tension structure for the tent shell. Bundles of cables with a diameter of 38 mm and length of 95-140 m, were stretched in pairs of blocks at a step of 70 cm. A 3D model of the tent was developed before applying tension in order to simulate behaviour of the tent on the cables. It showed that any snow that may accumulate in winter on one side of the tent will deform its entire surface. Also, it became clear that the structure needed certain kinematic properties to reduce the pressure on one of the sides of the shell. A movable unit 17 m high, 20 m in diameter capable of swinging in different directions during strong winds or snowfall with a displacement of 30 cm was developed instead of the movable spire. A network of cables stretched to 80% of the maximum load formed the shape of the Entertainment Centre. A temporary plastic roof was erected for interior works. German designers designed a shell made of 836 segments. A three-dimensional puzzle with an area of 20 thousand m^2 was developed. All segment pads of the roof have different shapes, sizes and individual locations in the overall structure [17]. The nets were stretched to allow the installation staff to move along the trimmers of the pad openings. The installation was difficult because the pads were mounted without air, and it was impossible to detect a puncture in the pads until they were inflated. Each pad was connected to a computer-controlled compressor. The pumping system delivered 60 thousand m^3 air at a low pressure to inflate each segment evenly to a width of 70 cm. It took seven hours to inflate the shell on the first try [18].

The fourth and final stage of the construction concerned the internal works on the interior, and preparation of the building for commissioning. The microclimate created by the ETFE material allowed hundreds of plant varieties from all over the world to take root and grow. Tropical temperature is maintained in the water park zone, whereas other parts of the centre have the temperature usual for the city climate. The climate of Astana always makes designers seek for new technical solutions. Even the most durable buildings get affected by the significant changes in temperature: the walls of buildings shrunk in the cold of winter and expand when it is hot in summer.

When creating the pyramid-shaped Palace of Peace and Reconciliation in Astana in 2010 as a symbol of tolerance and the unification of all world religions, architects and engineers had to deal with this issue (Figure 5). A project by British architect Norman Foster, which was later recognized as a masterpiece of world high-tech, was chosen through an international competition [11]. This building is popularly called a “Pyramid”. A number of innovative techniques were applied in order to construct this unique building in Astana. The harsh climate of the country was the main difficulty. In summer, the thermometer often rises to +40 ℃, and at night the temperature drops below zero; the temperature fluctuations in 12 hours may reach +40 ℃. In winter, when the wind blows from the Arctic, the gusts of this wind reach a hurricane speed of 200 km/h, and the temperature drops to -40 ℃.

Figure 5. Pyramid “Palace of Peace and Reconciliation” in the horizontal plane, 2006

Ensuring the pyramid's resistance to temperature variations proved to be challenging. Owing to the walls' pyramidal shape, their expansion and contraction could result in catastrophe or devastation [19]. The design engineers for Norman Foster came up with a solution: 40 column supports were positioned beneath the pyramid on unique sliding platforms, with 4 fixed columns and 36 movable columns that could go virtually wherever (Figure 6).

Figure 6. Assembled component of mobility of the Palace of Peace and Reconciliation building

The building foundation was laid in summer because the construction season in Kazakhstan lasts for as few as 6 months, and concrete may not be poured in winter. At that time, the building's whole superstructure—1000 triangle parts made of patented metal and glass—was constructed in England. The pyramid was put together as a building set by the planned strategy after the components were transported to the Astana construction site during the winter of 2006 [16]. The structure is completely lit by sunlight, even the underground levels, despite not having any windows. N. Foster has employed a sophisticated optical system of mirrors to let light enter the pyramid via the glass top and light the interior. The 130 doves in the stained-glass window at the summit of the pyramid, created by artist Brian Clark, represent the various ethnic groups who call Kazakhstan home [14]. An ingenious engineering solution – the use of a kinematic frame – has made it possible to create a “building-moving mechanism” that responds to the seasonal temperature fluctuations (Figure 7).

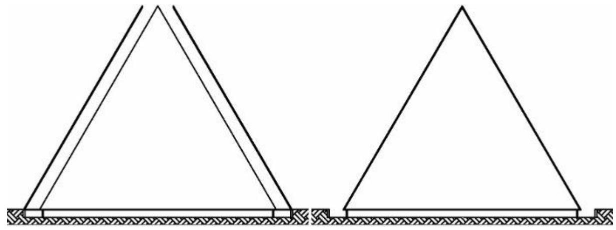

Figure 7. Diagram of building expansion in summer and shrinkage in winter

Global sustainable development programs have a resonance also in the architecture of Kazakhstan. The Talan Towers multifunctional complex, the first object in Kazakhstan that was certified according to the “green” LEED standard in the gold category, was built in 2017 in Astana taking into account possible dynamic loads and features of the strongly continental climate (Figures 8 and 9). The complex is recognized as the most energy-efficient and “healthy” architectural object in the country. Architects from more than 100 international companies, including SOM architect bureau, worked on this project [20]. The Talan Towers complex is a 30-storey international class “A” business centre and a 25-storey The Ritz-Carlton Astana luxury hotel with exclusive residences. Two towers have been designed according to the canons of “green” construction. Panoramic windows provide 90% of all areas with the natural sunlight, energy-saving glass optimizes the internal temperature in summer and winter [21].

Figure 8. Talan Towers, 2017, Astana

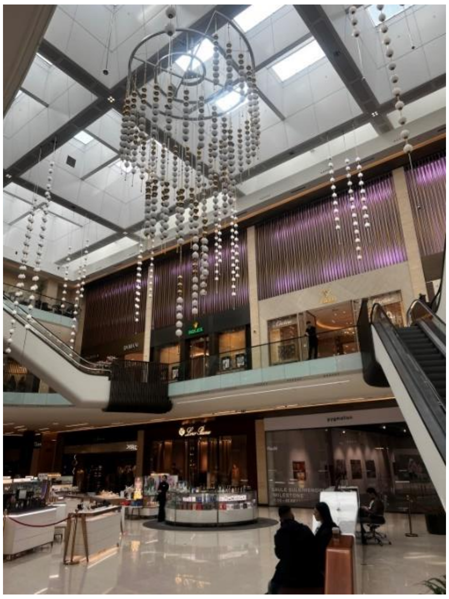

Figure 9. Gallery interior between the towers

External backlighting and lighting throughout the adjacent territory are powered by solar batteries with the possibility of uninterrupted operation on a single charge up to 36 hours. The use of green roof technology to reduce the effect of local overheating of the building has also contributed to the high certification rating. Plants are watered by drip irrigation with the rainwater being collected, which saves up to 92% water consumption. The "living" roof prevents air pollution and reduces greenhouse gas emissions, as well as improves the sound insulation of the complex. The building owners motivate tenants to use "clean" modes of transport. Exclusive finishing has been used in the outer cladding of the building. An old rock of marbled limestone or Jurassic stone mined in Germany will ensure the durability of the object, and resistance to environmental influences. The facade systems of the complex have successfully passed the seismic tests. The analysis of the dynamic test of the facade systems proved that the structure reliability had not been impaired even by the simulated vibrations exceeding by 1.5 times the values established for the grade 10 seismic areas. The test results showed that the facade systems have high mechanical strength to carry any dynamic loads [22, 23].

The issue of the sustainable development of the architecture and urban spatial environment supported with high-level engineering solutions is of top priority in Kazakhstan. This fact has been confirmed by the results of a questionnaire survey held by the authors of the article in December 2022-February 2023. The sociological survey involved 300 respondents related to the architecture and construction: students, undergraduates, doctoral students, practising architects, civil engineers, scientists and/or university professors. According to the respondents, the first step in designing solutions for Kazakhstan's local natural and climatic characteristics should be to tailor them to the country's most challenging problems, which include seismic activity and a severe continental climate (Figure 10).

The survey results, illustrated in Figure 10, highlight that the majority of respondents emphasize the need for architectural designs to adapt to the most challenging natural and climatic conditions of Kazakhstan. The specific concerns include: the highest concern, with 247 respondents (85.5%), is the adaptation to seismic hazards. Given Kazakhstan's history of significant earthquakes, especially in regions like Almaty, seismic resilience is a top priority. A substantial 239 respondents (82.7%) indicated that natural risks are a crucial factor. These natural phenomena can cause significant damage to structures and therefore need to be considered in the design and planning stages. 189 respondents, or 65.4%, mentioned that one must adjust to the harsh continental environment, which is marked by sharp differences between summer and winter temperatures. Strong winds are also a significant concern, as noted by 130 respondents (45%).

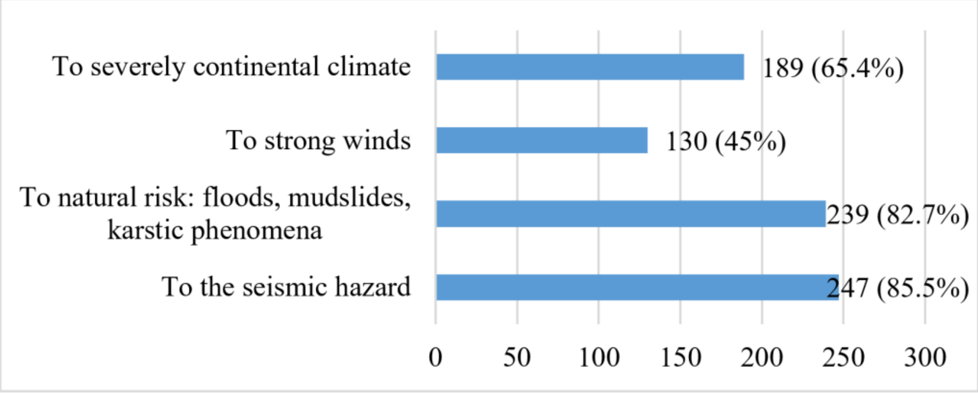

Figure 10. The main factors of the architecture adaptability in Kazakhstan

Most respondents agree that, in terms of seismic resistance, buildings in Almaty should not exceed five floors. However, it was also noted that with appropriate building area, choice of structures, and materials, buildings could safely reach up to 16 floors or higher. This indicates a balanced approach to urban development where safety is not compromised for height, provided the right engineering solutions are employed. The respondents consider frame and combined structural systems to be the most reliable in the context of Kazakhstan's challenging conditions. These systems provide the necessary flexibility and strength to withstand seismic activity and other environmental stresses. A significant portion of respondents believe that the architectural buildings and facilities constructed during the 1970s-1980s best met the highest technical requirements for Kazakhstan. This period corresponds to the Soviet state system of planning, implementation, and control in architecture and construction, which is still viewed as a reliable model by many experts.

Future research should focus on several key areas to enhance resilience and sustainability in the face of environmental and climatic challenges. Continued development of innovative materials and construction techniques to improve the seismic resilience of buildings is essential. Research could explore the use of smart materials that can adapt to seismic activity and incorporate real-time monitoring systems to predict and mitigate earthquake impacts. Further exploration of architectural designs that can withstand extreme temperature variations is crucial. This includes developing energy-efficient building envelopes, passive heating and cooling systems, and incorporating renewable energy sources to reduce reliance on traditional heating and cooling methods. Integrating green infrastructure and sustainable urban planning principles can enhance the livability and environmental performance of urban areas. Research could focus on the implementation of green roofs, urban green spaces, and water management systems that can adapt to the local climate. Engaging local communities in the planning and design process is crucial to ensuring that developments meet the needs and preferences of residents. Educational programs aimed at raising awareness about sustainable practices and resilience in architecture and construction can also play a significant role. Future studies can help design architectural and urban planning solutions that not only suit Kazakhstan's present demands but also assure long-term sustainability and resilience by tackling these areas.

The insights gained from this survey provide valuable guidance for future architectural and urban planning projects in Kazakhstan. They emphasize the need for a strong focus on seismic resilience, adaptation to extreme climate conditions, and the incorporation of reliable structural systems. Additionally, there is an appreciation for the technical standards set during the Soviet era, suggesting that future projects might benefit from integrating these historical practices with modern innovations.

4. Discussion

Characterization of the general concept of architectural and planning solutions in the engineering and construction industry of the Republic of Kazakhstan made it possible to justify individual engineering and construction transformations in connection with the trends and opportunities of scientific and technical progress in the context of preserving the cultural heritage of Kazakhstan. The survey of 300 respondents made it possible to understand that consumers need to be more informed about the latest achievements in architectural design and technical construction, because when making decisions about balanced complex infrastructure planning in rather risky natural and climatic conditions, the position of the public should be taken into account. Taking into account this crucial aspect, rapid socio-economic development of urban architecture will take place in the context of modern innovative and traditional approaches to construction.

D. Pohoryles et al. [17] analysed the problem of inconsistency of engineering architectural solutions in many regions of the world with modern needs of the population and changes in natural and climatic conditions. The excessive energy use of the existing structures for cooling and heating made a major portion of them unprofitable. By making major improvements to their energy efficiency, retrofitting could lessen their influence on the amount of energy used by households overall and the emissions of greenhouse gases. Recent earthquakes in seismically active areas have resulted in large financial losses, primarily from the susceptibility of older structures that don't adhere to new building codes. Integrated exoskeleton solutions, bolstering the insulation of the current enclosing structures before replacing them with better materials, and executing intricate interventions on horizontal elements like the roof and floor slabs are pertinent strategies to justify at the same time. The most efficient approach is to identify the route towards integrated seismic and energy upgrading of buildings. The enormous potential of these solutions is highlighted by a critical examination of their effectiveness, degree of interference, operational disruptions, and environmental impact. These solutions may offer reasonably priced options for reconstruction in areas with moderate to high seismic risk. This study made it abundantly evident how important it is to update buildings' energy systems while taking the risks associated with designing in seismic zones. Nevertheless, more work on integrated technologies and their validation through use on large-scale buildings that are already in place was not possible due to a deficiency of experimental research in this area. The current research results also spoke about the need to develop design methods that could be quickly adapted to natural and climatic changes and integrated into innovative modernization approaches [24].

A balanced environmental policy and environmentally friendly technologies and materials in construction are important prerequisites for achieving the climate and energy goals of the European Union [25]. At the same time, it is important to have a practical innovation approach as noted by C. Menna et al. [26], which aims to support the process of effective evaluation and decision-making during modernization planning. In addition to issues of energy efficiency, for some regions it is necessary to increase the resistance of buildings to natural hazards, in particular seismic activity. Analysing the state of applied integrated approaches for undertaking energy and structural modernization is crucial. An evaluation of current resources, global sustainability guidelines, and techniques created especially for integrated energy and seismic assessment are all included in the task. The assessment is conducted using the first set of procedures, quantified in compliance with current rules, regardless of the energy efficiency and seismic safety requirements. The second group's integrated assessment is made possible by accounting for "equivalent" life-cycle costs or initial expenses about seismic vulnerability and energy consumption. This study reaffirms the necessity of assessing all approaches that satisfy the quantitative and qualitative standards for the best possible integration of the engineering solution's life cycle and other crucial markers of the construction project's operation. As in the above-described research results, in the final analysis of this work, emphasis is placed on promising areas of research in the direction of sustainable and effective modernization of existing buildings of the Republic of Kazakhstan.

A. Samy [27] studied the basic principles of the operation of smart materials technologies in construction, which are an innovative approach aimed at using materials with built-in functions and the ability to respond to external ecological and anthropogenic factors. These technologies open wide opportunities for increasing the productivity, safety and sustainability of building structures. Smart materials can include sensors that measure various parameters, such as temperature, humidity, and pressure. Materials that are able to change their shape or properties depending on temperature or other external factors can be used to automatically regulate the thermal regime of a building. Electrochromic and thermochromics materials can change their transparency or color according to electric current or temperature, which can be used to control lighting and heat consumption in a building. Using materials that can store and release energy can contribute to more efficient energy use in buildings. Smart materials technologies can be incorporated into the 3D printing process, opening up new opportunities for fast and accurate construction [28]. This work also examines the issues of sustainable development of architecture and the urban spatial environment, supported by high-level engineering solutions, in particular, on a concrete example of modern architectural thought – the multifunctional complex Talan Towers, the first object in Kazakhstan certified according to the "green" LEED standard. The article substantiated the main principles according to which the complex was recognized as the most energy-efficient and "healthy" architectural object in the country. Architects from more than 100 international companies, including SOM architectural bureau, worked on the project. Therefore, the use of smart materials in construction can contribute to the creation of energy-efficient and sustainable buildings, while increasing the overall quality and functionality of buildings.

Energy-efficient vernacular architecture has several features that affect indoor thermal comfort and can be used to adapt modern architecture to modern lifestyles. Traditional vernacular architecture uses materials available in the region. This can include natural and local building materials, which have high thermal insulation and help retain heat indoors. Vernacular architecture often uses optimised forms and structures that promote efficient air circulation and heat dissipation. Such solutions can be used in modern buildings to improve ventilation and heat consumption according to S. Chandel et al. [24]. Traditional architecture can include intelligent use of natural light, as well as traditional heating and cooling methods such as solar collectors, artificial ventilation systems and architectural elements to create shade. At the same time, minimization of energy losses through walls, windows and roofs is usually taken into account. The use of heat-insulating materials and energy-efficient windows in modern architecture can significantly improve the thermal characteristics of buildings. Traditional architecture often creates harmonious connections with nature. Green roofs, courtyards and the use of natural elements can help retain heat and create natural thermal comfort [29]. The folk style, the use of local building materials, and the application of specialised engineering solutions comprise the researched concept of traditionalism. These strategies are intended to create a sustainable structure that takes into account the risks associated with the seismic zone as well as the natural and climatic conditions. That is why the adaptation of principles in modern architecture, which are highlighted in the work of Indian scientists, can contribute to the creation of energy-efficient buildings that meet modern requirements and lifestyles, while providing a high level of thermal comfort.

5. Conclusions

Kazakhstan has developed into a test bed for novel engineering approaches in the design of distinctive buildings, modifying constructions to suit regional climates. At the current stage of the country's development, socio-economic conditions allow improving the quality of architecture using the most advanced innovative technologies. In the 21st century, Astana demonstrates examples of adaptation of architecture to sharp temperature changes. Bold and interesting technical solutions make it possible to build buildings and structures that are unique in form and content for this city. It was in Astana that the architectural company of N. Foster built the shopping and entertainment complex “Khan Shatyr” using innovative materials and engineering technologies to create a comfortable microclimate (including a subtropical beach) and a spectacular building shape, which in 2006 was recognized by Forbes style magazine as the highest tent-type building in the world. A three-legged structure was built here for the first time, which, in combination with high-strength concrete and steel, was able to withstand all natural risks.

Modern 3D modelling of the behaviour of the building in different climatic conditions allows to prevent many risks even at the design stage. For example, in Astana, it was not possible to realize the pyramidal shape of the Palace of Peace and Reconciliation (architect N. Foster) due to sharp changes in air temperature. The walls' expansion and contraction will be destroyed because of their pyramidal design. For the construction of this object in local conditions, a kinematic frame was used for the first time: the columns of the pyramid formed a completely mobile frame, where only 4 columns out of 36 were statically fixed. The devastating earthquakes that occurred in Syria and Turkey in February 2023 showed that there are problems with standards and technologies in the construction industry. The examples discussed in this study show that the complex natural conditions of any construction require appropriate innovative engineering approaches. The final prerequisite is particularly crucial for building development in seismically active or harshly continental climatic locations. For this, it is necessary to study methods of increasing the stability of architecture and engineering ways of implementing such approaches, taking into account both traditional and innovative technologies.

Prospective areas of research should be based on studies of complex energy-saving systems, including the use of solar panels, geothermal energy and other renewable energy sources. The investigation and application of environmentally friendly and sustainable building materials, together with the creation of "smart" building management systems for the economical use of water, electricity, and other resources, contribute to lessening the environmental impact of the construction sector. The aspects of social infrastructure and public spaces must be considered in the development of architectural solutions for the creation of secure urban and public spaces in the event of natural disasters. Studying flexible and adaptive infrastructural solutions will allow adequate response to climate change and seismic activity. These areas of research can contribute to the creation of more sustainable and energy-efficient facilities adapted to the climate and seismic environment of Kazakhstan.

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